RECENT PRACTICE IN THE LOCOMOTIVE ENGINE ... COMPRISING THE LATEST ENGLISH...

Daniel-Kinnear Clark, Zerah Colburn

RECENT PRACTICE

IN

THE LOCOMOTIVE ENGINE:

(BEING A SUPPLEMENT TO "RAILWAY MACHINERY,")

COMPRISING THE LATEST ENGLISH IMPROVEMENTS,

AND A TREATISE ON THE

LOCOMOTIVE ENGINES OF THE UNITED STATES.

ILLUSTRATED BY A SERIES OF PLATES, AND NUMEROUS ENGRAVINGS ON WOOD

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PREFACE.

This Work is designed to illustrate and investigate the practice of English Locomotive Engines at the present day, and to present the most recent attainments in American practice.

The following exhibition of recent practice may also be accepted as, in some measure, supplementary to the Work on Railway Machinery by one of the authors. Certain topics of importance, therein treated with comparative brevity, are herein examined and discussed at considerable length. The Construction of Boilers and the Practice of Coal Burning are the departments in which chiefly Railway Locomotive Engineering has progressed, and, in the English division, they occupy accordingly by far the largest amount of space in the Work.

With respect to the Construction of Boilers, the improvements in the manufacture of iron and steel have very greatly promoted the excellence of steam-boilers for high-pressure; and the valuable experimental results that have been obtained on the strength of rivetted and welded plate joints, herein related at length, are likely to prove of essential service to the builders of high-pressure boilers, in the distribution of material and the construction of the joints.

As to the second principal subject of the English division—the working of the boilers, the combustion of fuel, and the generation of steam—the whole question of the combustion of coal, and its use in locomotives, is treated completely and in great detail, and is profusely illustrated by wood-cuts. It is clear that the universal abandonment of coke as fuel, and a reversion to the use of the combustible in its normal condition as coal, will, in the course of a few years, become an accomplished fact, as it is now in rapid progress of fulfilment. The immediate motive for such a change of practice is the necessity for reducing the expenditure on railways, in order to raise the dividends. As the cost of coke is necessarily greater than that of coal, and inasmuch as, under a proper system, a pound of coal does as much duty as a pound of coke—frequently more—there is, of course, economized the whole difference in cost of the two descriptions of fuel. But there is the nuisance of smoke to contend with on the railways using coal, when the coal is not completely burned, and the smoke prevented, particularly in running without the steam on, and in waiting at stations. In the following pages it will be shown, that the problem of smoke-prevention on railways has been fully solved—that by simple means smoke may be prevented with efficiency and economy. The term "smoke-nuisance" is relative in its signification, dependent on the views and tastes of railway travellers; but the term "smoke-prevention" is absolute; and those systems by which smoke is entirely prevented must be considered the best.

The Safety-valves of Locomotives have received further illustration and discussion in this Work; and the interest attached to this question is all the greater, by reason of the comparative frequency of boiler-explosions. Prompt action and ample area of escape are the things wanted in a safety-valve; such as are sufficient to prevent, under any circumstances, the elevation of the pressure in the boiler materially above that to which the safety-valve is adjusted.

In the Mechanism of the Locomotive, there has been nothing new worthy of special notice, with the exception of one or two simplified varieties of piston, the straight-link motion, and the horse-foot tyre. Additional evidence is adduced to show the advantage of balancing the reciprocating mechanism of the engine, in promoting the steadiness of the locomotive at high speeds, and the economy of fuel.

A summary notice of the most recent modifications in the working proportions and arrangements of locomotives is added.

With respect to the American division of this Work, written by Mr. Zerah Colburn, it is a record of American experience from an American point of view, and may be studied with advantage by English engineers. It is

interesting for the originality and research it displays, and it is valuable for the really practical information it affords. Mr. Colburn is a locomotive engineer of acknowledged standing, well known and appreciated in the United States for his general ability and practical acquirements. He and Mr. A. L. Holley, of New York, a rising engineer, are the joint authors of a very useful and original work on EUROPEAN RAILWAYS, to which the reader is referred for a useful and suggestive discussion on the comparative merits of European and American railways.

A History of the Introduction and Progress of Locomotive Engines in the United States introduces the American division, and there is no doubt that such a history, now for the first time published, will be received with great interest by English as well as by American readers. An analytical account of the characteristic features of American engines is added, showing that, in the United States, locomotives have gradually subsided into one great pattern for passenger traffic, and into a very few patterns for goods traffic, under the various conditions of such traffic.

Considerable space, also, is devoted to the Materials employed in American locomotives, as well as to the constructional details; and a valuable chapter is added on the Coal-burning locomotives of the United States.

The engraved illustrations embody the best and most recent practice of the present day, both in England and in the United States; and a comparison of the various English designs with the few American examples, will suggest to most people the expedition with which the American mind, untrammelled by precedent, can arrive at practical conclusions.

D. K. CLARK.

11, ADAM STREET, ADELPHI,
LONDON, *December*, 1859.

CONTENTS.

DIVISION I.—ENGLISH LOCOMOTIVES.

ANATOMY OF THE BOILER.

PHYSIOLOGY OF THE BOILER.

OF FUEL AND COMBUSTION.

PHYSIOLOGY OF THE BOILER.

HEAT-TRAPS, STEAM, &c.

OF THE ENGINE.

DIVISION II.—AMERICAN LOCOMOTIVES.

DETAILS OF CONSTRUCTION.

COAL-BURNING LOCOMOTIVES.

LIST OF PLATES.

The Plates are numbered in continuation of the Series in the Author's work on Railway Machinery.

DIRECTIONS FOR THE BINDER.

In binding this book, the engravings are to be mounted on guards of stout cartridge paper, of such a length, that, when sewed, the distance from the back of the book to the back edge of the engraving pasted down, will be 1½ inch. The letter-press is to be mounted on guards of the same length, and the inner half of each sheet pasted into the outer before it is mounted. Short intermediate guards are to be inserted to make up the thickness of the back in the usual way of a guarded book. The engravings are to be placed in the order of their numbers, and are to follow the letter-press.

LIST OF WOOD ENGRAVINGS.

RECENT PRACTICE

IN

THE LOCOMOTIVE ENGINE.

DIVISION I.—ENGLISH LOCOMOTIVES.

ANATOMY OF THE BOILER.

CHAPTER I.

On the Tensile Strength of Boiler Plates.

As the demand for power increases in the locomotive, there is a corresponding necessity for steam at very high pressure. Working pressures varying from 100 lbs. to 150 lbs. per square inch are now common in locomotive-boilers, and the question of the tensile strength of boiler-plate rises into importance. It is needful to determine the absolute strength of the solid plate, distinctly from that of the rivetted plate, and to find in what way the strength of plates may be the least affected by the unavoidable rivetted seams,—unavoidable at least in existing practice.

1st, *With respect to the Strength of Solid Plates.*—The earliest recorded trials of the strength of boiler-plate, are those of Mr. Fairbairn, made in 1838, in which he found the tensile strength of plates of the subjoined denominations, in the direction of the fibre, and across the fibre, as follows:—

Plates.	With Fibre.	Across Fibre.	Mean.
	Tons per inch.	Tons per inch.	Tons per inch.
Yorkshire,............	24·27	26·76	25·51
Derbyshire,..........	21·68	18·65	20·16
Shropshire,..........	22·83	22·00	22·42
Staffordshire,........	19·56	21·01	20·30
Means,............	22·08	22·10	22·10

Upon the whole, the longitudinal and cross strengths are practically the same, 22 tons per square inch.* But, in particular cases, considerable differences are observable between the longitudinal and the cross strengths, due probably to the particular modes of piling adopted in the manufacture. The Yorkshire plates are markedly stronger than the others, having a tensile strength of 25½ tons per square inch; that of the others averaging 21 tons per inch.

Mr. Edwin Clark, again, found, from various trials of boiler-plate from Derbyshire, Shropshire, and Staffordshire, that the results were nearly alike with the different samples; that the mean tensile strength with the grain was 20 tons per square inch, and across the grain 17 tons per inch.† These results, though they do not entirely accord with those of Mr. Fairbairn, show the propriety of placing the fibre of boiler-plate in the direction of the greatest strain.

In the course of experiments conducted by Mr. Brunel, to be subsequently discussed, the breaking weight of Staffordshire boiler-plates was found to average 20·6 tons per square inch, with plates ¼ and ½ inch thick; and it was not materially affected by the thickness. By recent tests at Woolwich dockyard, the tensile strength of Staffordshire plates, varying in thickness from ⅜ inch to ½ inch, was found to be uniformly about 20 tons per square inch of section, independently of the thickness.

The best American boiler-plate for locomotives is stated by Mr. Zerah Colburn to have a tensile strength of 70,000 lbs., or above 31 tons per square inch of section; and that of the ordinary plate for locomotives, is said to be 60,000 lbs., or 27 tons per square inch.

Cast-steel boiler-plate is manufactured at Sheffield, of great strength, tenacity, and toughness. It is said to have a tensile strength of 40 to 45 tons per square inch; and to make excellent boilers.

Upon the whole, English boiler-plates are of two classes—Yorkshire, and the manufacture of other districts classed together as "Staffordshire." The ultimate tensile strengths of boiler-plates for locomotives, average as follows:—

Best‡ Yorkshire iron plate, per square inch,			25 tons.
Best Staffordshire iron plate,	"	"	20 "
Best American iron plate,	"	"	31 "
Ordinary do. do.,	"	"	27 "
Cast-steel plates,	"	"	40 "

* Mr. Fairbairn's mean results, deduced from these experiments, are 22·5 tons and 23 tons respectively for the longitudinal and cross strengths of the plates. His higher averages are procured by making two separate entries of Yorkshire plates, which are in the above quotation entered as one result.

† Britannia and Conway Tubular Bridges, 1850.

‡ When we say "best," we mean best; that is to say, good in the superlative degree: not employing the phraseology of the manufacturers, who would call a superlatively good plate, "best, best, best."

Influence of Temperature on the Strength of Plates.—Mr. Fairbairn found experimentally* that the strength of ordinary Staffordshire plates, either with or across the grain, remains unaffected at all temperatures from 0° to 400° Fah. At higher temperatures, the strength declines, until, at a red heat, it falls from the ordinary average of 20 tons per inch, to 15¼ tons per inch. The highest temperatures to which the shells of locomotive-boilers are exposed, is that of the steam they contain, which is much below 400°, being but 388° for 200 lbs. steam, and 350° for 120 lbs. steam. Consequently there is nothing to fear from the high temperature in which boilers are worked.

Strength of Copper Plates.—In copper for fire-boxes, soundness of material is wanted, rather than strength. That is to say, the strength of firebox-plates, is, as ordinarily put together, much under-tasked; for, as a cubical chamber composed entirely of flat surfaces, the fire-box is stayed at all points. It will be shown, in a succeeding chapter, how effectually the system of stay-bolts provides the necessary power of resistance.

The ultimate tensile strength of copper is 16 tons per square inch, according to the results of experiments by Mr. Fairbairn on stay-bolts, to be noticed subsequently. Its resistance to compression is said to be only 3 tons per square inch.

CHAPTER II.

On the Tensile Strength of Rivetted Joints of Boiler-Plate.

Joints are formed variously:—by lapping the plates, in the ordinary way; by butting the plates, and covering the seam with a welt or strap. They are rivetted together with a single row of rivets; or they may be double-rivetted, with two parallel rows of rivets, alternating or zigzag. The question is, Which is the strongest joint?—how much is the available strength of the plate reduced by the joint? There is another question, Whether the rivet-joint is not likely to be superseded by the welded joint?

Mr. Fairbairn's Experiments.—Mr. Fairbairn, in 1838, deduced from experiment, that double-rivetted lap-joints were stronger than those single-rivetted; and that their relative values were as follow:—

Tensile strength of the solid plate, ...	100
Tensile strength of the double-rivetted joint, ...	70
Tensile strength of the single-rivetted joint, ...	56

That is, the double-rivetted joint has but 70 per cent. of the tensile strength of the unpierced solid plate; and the single-rivetted joint only 56 per cent.

Mr. Edwin Clark on the Grip of Rivets.—Mr. Clark contends that the grip of the rivet-heads on the plates, supplies an important element of strength to the joints, in virtue of the frictional resistance to the sliding of one plate on the other, due to the grip. The friction due to the shrinkage of one ⅞-inch rivet, was found by rivetting one plate between two or more plates, varying the number and thickness of plates, to try the effect of length of rivet upon the grip. He tried three ⅝-inch plates rivetted together, with one ⅞-inch rivet, the middle plate having an oblong hole; he then added two ½-inch plates. He also tried two 5/16-inch plates with two 5/16-inch washers. In the three cases, then, the rivets were respectively 15-8ths, 23-8ths, and 10-8ths long on the shank. Arranging the trials in the order of the length of rivets, the frictional resistances were found as follows:—

Shank	10-8ths long.	Frictional resistance		4¾ tons.
Do.	15-8ths long.	Do.	do.	5½ tons.
Do.	23-8ths long.	Do.	do.	8 tons.

Showing that the longer the shank, up to about 3 inches in length at least, the greater the grip. Length may be excessive, however, for, with shanks above 6 or 8 inches long, the heads are frequently drawn off, when the strain by shrinkage equals the tensile strength of the metal. It seems difficult of explanation, why a long rivet should be strained more than a short rivet, as the proportion of shrinkage to the length, and therefore also the grip, are naturally presumed to be constant for all lengths. The increase of grip is probably due to the same law that regulates the extension of bolts subjected to tensile strains, according to which the rate of elongation per unit of length, decreases in some ratio as the length increases, with the same tensile strain. Conversely, the enforced elongation of rivets in cooling, or, more correctly, the resistance opposed to shrinkage, would, under this law, be greater, in proportion to the length, until ultimately it would, as in fact it does, equal the entire strength of the rivet.

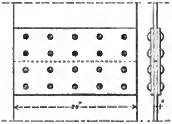
Whilst the friction by grip of rivet-heads, aids the plates in their resistance to a rupturing strain, the transverse strength of the rivets themselves, to resist what Mr. Stephenson has called the shearing strain, must be reduced:—probably in proportion to the grip. It does not, therefore, necessarily follow, as Mr. E. Clark seems to argue, that because the grip is accompanied by frictional resistance to sliding, between the two plates, the strength of the joint is by so much increased. The longitudinal tension on the rivet, inducing grip, reduces its power of resistance to the shearing strain, because forcible elongation is equivalent to partial fracture; when excessive, as has already been seen, it results absolutely in fracture, in which case, of course, the resistance to shearing becomes nothing. Upon the whole, it is probable that the total resistance of a rivetted joint is not materially increased by the friction of grip, but is measured, on the part of the rivets, by their transverse sectional area; on the part of the plate, by its sectional area between and in the centre line of the rivet-holes.

Mr. Brunel's Experiments on Rivet-Joints.—Some years since, Mr. Brunel experimented on rivetted-plate joints on a large scale; the plates were 20 inches wide, and ½ inch thick, butt-jointed, with a fishing plate on each side, 9 or 10 inches deep, and ⅜ inch thick, put together with rivets, as in the sketch, Fig. 1. Two pairs of plates, of best Staffordshire iron, were thus joined with 11/16-inch rivets, ten through each plate, being precise duplicates of each other. On being drawn asunder, the first pair failed with a force of 153 tons; the ten rivets in the upper plate having been cut through, and the plate

* *On the Tensile Strength of Wrought Iron at Various Temperatures*, 1857.

extracted whole. In the second pair, the rivets stood firm, and one of the plates was torn through the outer line of rivet holes, with a force of 164 tons. Hence, it is inferred, the strength of the rivets, upon the whole,

Fig. 1.—Scale, One-twelfth.



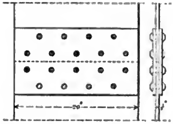
Rivetted Plate-Joint. Tested by Mr. Brunel.

balanced that of the plates; the mean strength of the joint being 158·5 tons. The total sectional area of ten $\frac{11}{16}$-inch rivets, is $·375 \times 10 = 3·75$ square inches; and twice this area, or 7·5 square inches, is the amount of shorn surface, each rivet having been cut at two places. Then, the fractured plate had $20 \times \frac{1}{2} = 10$ square inches of solid section; and the section taken through the rivet-holes is less than this by $\frac{11}{16} \times \frac{1}{2} \times 5 = 1·75$ square inch, which is the area of section punched out; and $10 - 1·75 = 8·25$ square inches, is the area of the fractured section. The area of shorn surface of the rivets is then $\frac{3}{4}$ square inch, or about 9 per cent. less than that of the punched section of the plate. Two other duplicates, the same as the first in all respects, except that they had $\frac{3}{4}$-inch rivets, were also tested; and they failed, in each case, through one of the plates in the outer line of rivet-holes, with loads of 167 tons and 147 tons respectively; giving a mean of 157 tons breaking weight. The total sectional area of ten $\frac{3}{4}$-inch rivets, is 4·5 square inches, which, doubled, amounts to 9 square inches of section to resist shearing. The sectional area of the plate, in the line of the rivet-holes, is $20—(\frac{3}{4} \times 5) \times \frac{1}{2} = 8·125$ square inches; and thus the sectional area to resist shearing, is ·875 inch, or 10 per cent. more than that of the punched plate.

Practically, then, the two rivetted joints, made with $\frac{11}{16}$-inch and $\frac{3}{4}$-inch rivets respectively, were found to be equally strong, as the mean breaking weights were respectively 158·5 tons and 157 tons. In the former, the sectional area of rivets to resist shearing, is 9 per cent. less than that of the punched plate; and in the latter, it is 10 per cent. more. It may thence be inferred, that the maximum of strength is obtained when the united sectional area of the rivets, to resist shearing, is equal to the sectional area of the plate through the rivet-holes; or, otherwise, when the united sectional area, simply, of the rivets, is equal to half the sectional area of the punched plate.

In the same series of experiments, a number of joints, arranged as in Fig. 2, were tested with Staffordshire plates and fishes of the same dimensions as those just described; and $\frac{3}{4}$-inch rivets, five in the middle rows, and four in the outer rows, zig-zag, or, say, Vandyke pattern. Four joints were broken, with 158, 160, 161, and 168 tons respectively, or a mean breaking weight of 162 tons. The fracture of the plate followed, in one case, the zig-zag course of the rivets, and in two cases, the rivets partly failed; showing, upon the whole, a set of well balanced joints, and proving that a double row of rivets alternating or zig-zag, makes a rather stronger joint than a double row of rivets in pairs, as previously tested.

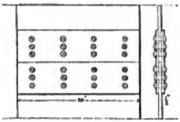
Fig. 2.—Scale, One-twelfth.



Rivetted Plate-Joint. Tested by Mr. Brunel.

A third variety of joint was tested, having three rows of rivets in line, and only four rivets in each row, as in sketch, Fig. 3. With the same size and quality of plate and fishes as before, and $\frac{3}{4}$-inch rivets, two joints on this

Fig. 3.—Scale, One-twelfth.



Rivetted Plate-Joint. Tested by Mr. Brunel.

plan, carried respectively 171 tons and 176 tons of breaking weight, or a mean of 173·5 tons, proving this to be decidedly the strongest joint of all. In this case, the rivets, twelve in number, had 10·8 square inches of shearing section, and the plate 8·5 square inches of section in the line of the rivet-holes. There is no doubt that the reduction of the number of rivets in the row from five to four, compensated by an extra row behind, is the reason of the extra strength of this joint.

The strength of the three varieties of joints may now be compared with that of the solid plate. Mr. Brunel broke five solid Staffordshire plates $\frac{1}{2}$ inch thick, and 12 to 16 inches wide, of the same quality as used in the joints; the breaking weight varied from 19·4 to 22 tons per square inch, and the mean result gave 20·6 tons breaking weight per square inch of section of solid plate. The mean breaking weight of the zig-zag rivet-joint was 20 tons per square inch of solid section in the straight line of the rivet-holes; and that of the joints with three rows of rivets, was 20·4 tons per inch; showing that the strength of the material was practically unimpaired by the punching; and that the strength of the well balanced rivetted joints, was simply in proportion to the transverse sectional area of solid metal in the main line of rivets. The comparative strengths of the solid plate, the zig-zag double-rivetted joint, and the parallel triple-rivetted joint, are then as follows:—

	Tensile Strength.
Solid plate, per square inch, ...	20·6 tons, or, say, 100.
Zig-zag double-rivetted joint, per square inch of the solid plate, ...	16·2 tons, or as 79.
Parallel triple-rivetted joint, per square inch of the solid plate, ...	17·35 tons, or as 84.

That is, the zig-zag double-rivetted joint, with double fish-plates, retains four-fifths of the entire strength of the metal, and the triple-rivetted joint retains five-sixths.

These results are superior to those of Mr. Fairbairn on lap-joints, and the double fish-plate, or a double-welt, could be applied with advantage to the joints of steam-boilers. The double fish or welt doubles the effective resistance of rivets to shearing, as compared to their resistance with single welts, or in lap-joints; and with double the resistance, half the number of rivets would give the same strength to the joint, and would afford a larger remainder of solid section of plate in the line of the rivet-holes. In ordinary double-rivetted lap-joints, 30 per cent. of the perforated section is occupied by rivets; whereas, in the proposed double-welted joint with double rivetting, there needs not, according to Mr. Brunel's experiments, be more than 19 per cent., or one-fifth, deducted for rivet-holes. Assuming that the full advantage of the double welt would be available, the tensile strength so reclaimed would be one-seventh, or 14 per cent., more than that of the ordinary double-rivet joint, or an additional 10 per cent. of the strength of the entire plate.

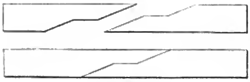
Yorkshire plates, from Leeds and Bowling, were jointed with double welts and double rivets, according to the sketch, Fig. 2, and were tested by Mr. Brunel like the others. The average result of four cases was a breaking weight of 173 tons, or 17·3 tons per square inch of section of the entire plate.

CHAPTER III.

On the Tensile Strength of Rivetted Joints of Boiler-Plate (*continued*).—Tensile Strength of Welded Joints.

Mr. W. Bertram's Process for Welded Joints: Experiments on Welded and Rivetted Joints.—Mr. Bertram, of Woolwich, has, under a recent patent, invented an original process for welding the joints of iron plates, to super-

Fig. 4.—Full Size.



Bertram's Scarf-Welded Plate.

sede rivetting. An extensive series of experimental trials of the tensile strength of plate-joints was made at Woolwich, comprising two welded joints, the scarf-weld, and the lap-weld, with the usual varieties of rivet-joints. Staffordshire plates of good, sound, uniform quality, were carefully selected for the trials; of three thicknesses, ½ inch, 7/16 inch, and ⅜ inch, made up into specimens 4 inches broad, 24 inches long, in which the rivet-joints were made with ¾-inch rivets at 2 inches pitch, affording a valuable collection of comparative results. The scarf-weld was made as in Fig. 4, which shows the prepared edges, and the completed weld. The lap-weld was made as in Fig. 5, with 1¼-inch lap, though in practice this has been reduced to ¾ inch. Three specimens of each variety of joint, for each thickness of plate, were tested, and the results were averaged for each set of three specimens. The tensile strengths of the solid plates were tested, with very uniform results, showing a breaking weight of 20 tons per square inch of section, for all the thicknesses. The varieties of joint tested were, the weld-joints, in two varieties, the scarf-weld, and the lap-weld; single-rivetted joints, in four varieties, by hand, by the machine, and with countersunk heads; double-rivetted joints, in three varieties, ordinary lap snapheaded, and countersunk and snapheaded,

Fig. 5.—Full Size.

Bertram's Lap Welded Plate.

and with a single welt. These joints are illustrated by Figs. 6–15. The fractures took place, in nearly all cases, in one of the plates, in the line of the rivet holes. In a few cases, the rivets were shorn across. Table No. I. comprises results of important tests made with a view to show the superiority of the welded joint.

TABLE No. I.—OF THE TENSILE STRENGTH OF WELDED AND RIVETTED JOINTS OF BOILER-PLATE.

Tensile Strength of the Entire Plate, 20 Tons per Square Inch.

Number in the Series.	Name of Joint.	Form of Joint.	Ultimate Tensile Strength of Joint, that of the Entire Plate being = 100.			
			Half-inch Plate.	Seven-sixteen Inch Plate.	Three-eighth Inch Plate.	Mean Strength of Three Thicknesses.
			Per-centage.	Per-centage.	Per-centage.	Per-centage.
1.	Entire plate.	Fig. 6.	100	100	100	100
2.	Scarf-welded joint.	Fig. 7.	Faulty	106	102	104
3.	Lap-welded joint.	Fig. 8.	50	69	66	62
4.	Single-rivetted joint, by hand.	Fig. 9.	40	50	60	50
5.	Single-rivetted joint, by hand, snapheaded.	Fig. 10.	50	52	56	53
6.	Single-rivetted joint, by machine.	Fig. 11.	40	54	52	49
7.	Single-rivetted joint, with countersunk heads.	Fig. 12.	44	50	52	49
8.	Double-rivetted joint, snap-headed.	Fig. 13.	59	70	72	67
9.	Double-rivetted joint, countersunk and snapheaded.	Fig. 14.	53	73	69	65
10.	Double-rivetted joint, with single welt, counter-sunk and snapheaded.	Fig. 15.	52	60	65	59
	General Averages of all the Lap-Joints, ...		48	60	62	57

Fig. 6.—Entire plate.

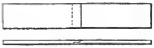


Fig. 7.—Scarf-welded joint.

Fig. 8.—Lap-welded joint.

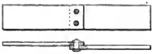


Fig. 9.—Single-rivetted joint, by hand.

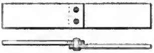


Fig. 10.—Single-rivetted joint, by hand, snapheaded.

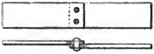


Fig. 11.—Single-rivetted joint, by machine.

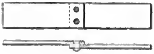


Fig. 12.—Single-rivetted joint, with countersunk head.

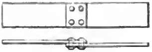


Fig. 13.—Double-rivetted joints, snapheaded.

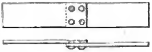


Fig. 14.—Double-rivetted joint, countersunk and snapheaded.

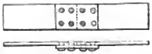


Fig. 15.—Double-rivetted joint, with single welt, countersunk and snapheaded.

BOILER-PLATE JOINTS, TESTED BY MR. BERTRAM.

Important inferences may be drawn from the contents of this table. First, the scarf-welded joint is fully as strong as the entire plate; and, referring to the last column, which contains averages of the three thicknesses selected for the trials, the lap-welded joint has but five-eighths, or 62 per cent., of the strength of the entire plate. The varieties of single-rivetted joints average equally strong with each other, and they have only one-half the strength of the entire plate, excepting the snap-headed, which is rather stronger. Of the double-rivetted joints, the ordinary lap is the strongest, having two-thirds of the entire strength of the plate; the welt-joint is weakest.

Comparing the different thicknesses of plate, the averages of all the lap-joints, at the foot of the table, show that, for the 7/16-inch and 3/8-inch plates, they are equally strong; and are above one-fourth stronger than for the 1/2-inch plate, relatively to the thickness of plate.

Leaving the general averages, the drift of the evidence is, that the thinner the plate the more efficient is the joint. The single-rivetted joints have successively 40, 50, and 60 per cent. of the strength of the entire plates; and the double-rivetted joints, 59, 70, and 72 per cent.; insomuch that the 3/8-inch single-rivetted joint is absolutely stronger than the thicker joints, for the actual breaking weights are successively about 16, 17, and 18 tons, for the 1/2-inch, 7/16-inch, and 3/8-inch joints; for the double-rivetted joints, the actual breaking weights are successively about 24, 24, and 22 tons, showing that the 7/16-inch joint is absolutely as strong as the 1/2-inch, and that the 3/8-inch joint has only one-twelfth less absolute strength than the others. The double-rivetted welt-joint, similarly, is more efficient for the thinner plates, and its absolute strength is practically the same for them all.

It appears, then, that 3/8-inch rivetted plates are, practically, stronger than 7/16-inch and 1/2-inch rivetted plates; and that, of the 3/8-inch joints, the double-rivetted lap is the most efficient, the welt next, and the single-rivetted lap next. Thus,

Entire plate, 3/8-inch thick, tensile strength,		100
Double-rivetted lap-joint,	do.	72
Double-rivetted welt-joint,	do.	65
Single-rivetted lap-joint,	do.	60

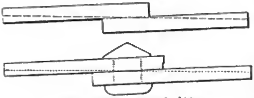
These proportions do not differ widely from those that have already been obtained by Mr. Fairbairn, though his values are too high for 1/2-inch plates. The startling circumstance is, that the 1/2-inch plates should have had no greater absolute strength at the joints than the 3/8-inch plates:—proving, seemingly, that a boiler of 3/8-inch plates is as strong as one 1/2-inch thick; indeed, absolutely stronger, if rivetted in the ordinary way.

The trials show that there is no superiority in machine-rivetting over rivetting by hand; that, for 3/8-inch plates, it is inferior. They show, further, that countersunk rivet-heads do not seriously impair the strength of the joint, as compared with external heads, button or snap.

Reverting to the welded joints, the 3/8-inch lap-weld has two-thirds of the strength of the entire plate, and the 1/2-inch has only one-half—showing that the absolute strengths of the two joints are the same. The lap-weld is decidedly stronger than the single-rivetted joint, but not so strong as the double-rivetted, the relative percentages for 3/8-inch joints being 60, 66, 72. The lap-weld is strikingly weaker than the body of the plate, notwithstanding the solidity of the joint, for here there is no weakening by punched rivet-holes. The weakness arises from the

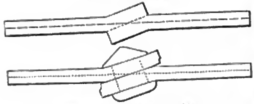
indirectness of the lap: the plate, though solid, is not straight. This experiment, though simple, is suggestive. It proves that the lap is essentially an element of weakness, irrespective of the loss of strength by rivet-holes. The weld being sound, fracture must take place in the solid plate on either side of the weld; and the strain being necessarily oblique with the centre lines of the plates, as sketched in Figs. 16, 17, showing the weld, and the rivet-joint, it must operate with a leverage, ultimately distorting the joints, as in Figs. 18, 19, and severing the plates by breaking them across. The thicker the plate, the greater the leverage and the transverse strain,—so

Figs. 16, 17.—Scale, One-half.



Diagrams to show Oblique Strain on Lap-Joints.

Figs. 18, 19.—Scale, One-half.



Ultimate effects of Oblique Strains on Lap-Joints.

much so, that the ½-inch lap-welded plate was not stronger than the ⅜-inch weld: it had only half the strength of the entire plate. On this principle, one may account for the practically equal strength of a joint made with countersunk rivets, compared with one having external rivet-heads, notwithstanding the greater loss of metal by the rivet-holes in the former case. The leverage in this case is shorter, and may be measured from the centre of the cylindrical part in the line *a a*, Fig. 20, or thereabouts,

Fig. 20.—Scale, One-half.

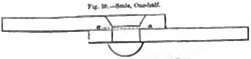
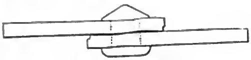


Diagram to show Strain on Countersunk Rivets.

towards the inner side of the plate. The superiority of the double-rivetted joint to the single-rivetted joint, also, may partly be ascribed to the greater extent of the lap, in virtue of which, though the leverage may be the same, the angularity of the strain, represented by Fig. 17, is diminished, and the power to resist distortion correspondingly increased. There is an element of strength in long-lap which is not in short-lap, and this explains why the lap-welded joint, in the trials, stands so low in the order of strength: the lap was limited to 1¼ inch, and, had it been made 2 or 3 inches in length, it would probably have stood next to the scarf-weld, superior to all the rivetted joints.

Touching the ordinary rivet-joint, the caulking process, necessary to close it steam-tight, is probably a cause of weakness; for it is known that the caulking buckles the

Fig. 21.—Scale, One-half.



Effect of Caulking on Rivet-Joints.

edges of the plates, as shown, exaggerated, in Fig. 21, tending to separate them.

The scarf-weld joins the two parts into one continuous plate, and, therefore, reasonably, the strength of the weld is, in fact, fully equal to that of the entire plate: rendering available for direct resistance, the whole strength of the entire section, whatever the thickness of plate.

The author has been enabled—through the kindness of Mr. A. H. Renton, C.E., from whose pamphlet, as well as personal explanations, on Bertram's process, he has derived much of his acquaintance with it—to examine several specimens of the welding process. In these examples, the welds were proved to be absolutely sound, by being dissected and scarified in various ways. He also witnessed the proving of a cylindrical boiler 4 feet in diameter, of $\frac{7}{16}$-inch plates, with an internal flue, all lap-welded, without a single rivet anywhere; it bore 150 lbs. per inch, water-pressure, without leakage, and was a satisfactory job. The welded edges of the plates were sharp and unburnt, of undiminished substance. The most delicate scarf-edges may be welded efficiently, as but very light hammering is necessary. Our conviction is, that rivetted joints are destined to be superseded by the welded joint. Independently of the greater strength obtained, the reduction of weight and the permanent freedom from leakage are most important considerations as respects its application to vessels subject to steam or water pressure.

CHAPTER IV.

Summary Conclusions on the Strength of Boiler-Plate Joints.

In concluding upon the relative strengths of different forms of joints, we are disposed to base our conclusions upon the results of Mr. Brunel's trials, and of the trials at Woolwich, detailed in previous chapters; and whereas, it has been assumed that, in rivetted boilers, the thicker plate is also the stronger, because it is the thicker, it appears that ⅜-inch rivetted plates are practically as strong as $\frac{7}{16}$-inch or ½-inch rivetted plates. There is, therefore, no advantage in the selection of plates, as usually rivetted, of greater thickness than ⅜-inch for boilers. The relative strengths of different forms of ⅜-inch rivet-joints have been found to be thus:—Single-rivetted lap-joints, 60 per cent. of the strength of the entire plate; double-rivetted lap-joints, 72 per cent.; double-rivetted single-welt joint, 65 per cent. The double-rivetted double-welted joints of

⅜-inch plates, tested by Mr. Brunel, had 80 per cent. of the entire strength; and ⅜-inch plates so jointed would doubtless be found to have an equally large percentage of strength. The strain, indeed, is applied in the centre line of the plates without leverage, and the joint should have the same percentage of strength for any thickness of plate. The double-welt thus makes the strongest of all the rivet-joints; and for Yorkshire plates, having 25 tons per inch ultimate tensile strength, it would have a resistance equal to 20 tons per square inch of the entire plate. The ultimate strength of double-rivetted single-welt joints, is 16¼ tons per inch; of double-rivetted lap-joints, 18 tons per inch; and of single-rivetted lap-joints, 15 tons per square inch of section, for Yorkshire plates.

For plates of best "Staffordshire" quality, having 20 tons per square inch absolute tensile strength, the ultimate strength with the double-rivetted double-welt joint, is 16 tons per square inch; with double-rivetted single-welt joints, it is 13 tons per inch; with double-rivetted lap-joints, it is 14½ tons per inch; and with single-rivetted lap-joints, it is 12 tons per inch.

Of the welded joints, the scarf-weld retains the whole strength of the entire plate, 100 per cent.; and the lap-weld retains 66 per cent.—which, for Yorkshire plate, would amount to 16½ tons, and for Staffordshire plate, 13 tons per square inch of section.

There is, however, a most important and peculiar element of strength in the ordinary lap-joints for circular seams, as distinguished from straight seams: in the circumstance that the circular lap-joint cannot possibly be distorted like the straight lap-joint, under extreme tension, in the manner depicted in Fig. 19, page 6*; for, in virtue of the circularity of the joint, the outer plate must be extended at the edge, and the inner plate must be compressed, in order to change the form, becoming, in fact, a conical joint, in place of a cylindrical joint. The resistance to such an alteration of form in the circular joint is so great that it cannot practically alter its form at all; and there is no doubt that, as the influence of lateral leverage is here neutralized, the absolute strengths of all the varieties of lap-joint applied circularly, increase with the thickness of the plates; but, on this particular question, there is a want of direct experimental evidence.

For the maximum working strength of the material of a boiler and the joints, the proportion of one-fifth of the ultimate tensile strength may safely be adopted. In selecting this proportion, we are fortified by the practice of wrought-iron bridge engineers, who adjust the dimensions of the lower members of such bridges to a working tensile strain of 4 to 5 tons per square inch: the metal so employed being of Staffordshire manufacture, supposed to have an ultimate tensile strength of 20 tons per inch, and, of course, something less than that at joints.*

The ultimate and working tensile strengths of plates, variously jointed, are placed together for reference, in Table No. II. The working strength is estimated, in all cases, at one-fifth of the ultimate strength.

* Mr. Fairbairn adopts only one-sixth of the ultimate tensile strength of the joint, for the maximum working pressure, in stationary cylindrical boilers; which, we think, is judicious, for boilers set in bricks and mortar are not permanently reliable. Brick-set boilers are a remnant of ancient practice, and must be set aside to make way for self-contained boilers of the locomotive stamp.

TABLE No. II.—OF THE ULTIMATE AND WORKING TENSILE STRENGTHS OF BOILER-PLATES AND JOINTS, DEDUCED FROM EXPERIMENTS WITH ⅜-INCH PLATES.

Quality of Plate; and Nature of Joint.	Percentage of Tensile Strength, that of the entire Plate being 100.	Tensile Strength. Ultimate Strength, per square inch of the entire section of Plate.		Working Strength per square inch of the entire section of Plate, taken at one-fifth of the Ultimate Strength.	
Best Lowmoor Plate.	Per cent.	Tons per Sq. Inch.	Lbs. per Sq. Inch.	Tons per Sq. Inch.	Lbs. per Sq. Inch.
1. Entire plate, ...	100	25	56,000	5	11,200
2. Scarf-welded joint, ...	100	25	56,000	5	11,200
3. Lap-welded joint, ...	66	16·5	36,960	3·3	7,392
4. Double-rivetted double-welt joint, ...	80	20	44,800	4	8,960
5. Double-rivetted single-welt joint, ...	65	16·25	36,400	3·25	7,280
6. Double-rivetted lap-joint, ...	72	18	40,320	3·6	8,064
7. Single-rivetted lap-joint, ...	60	15	33,600	3	6,720
Best Staffordshire Plate.					
1. Entire plate, ...	100	20	44,800	4	8,960
2. Scarf-welded joint, ...	100	20	44,800	4	8,960
3. Lap-welded joint, ...	66	13	29,120	2·6	5,824
4. Double-rivetted double-welt joint, ...	80	16	35,840	3·2	7,168
5. Double-rivetted single-welt joint, ...	65	13	29,120	2·6	5,824
6. Double-rivetted lap-joint, ...	72	14·5	32,480	2·9	6,496
7. Single-rivetted lap-joint, ...	60	12	26,880	2·4	5,376

NOTE.—1. For the strengths of the joints of American best plates, allow one-half more than for best Staffordshire plates; for ordinary American plate, one-third more; and for cast-steel plate, double.

2. The contents of the table are correct for ⅜-inch plates, and for thinner plates; but they are altogether too high for thicker plates.

In the order of strength, the joints range thus:—

1. Scarf-welded joint, ...	100	
2. Double-rivetted double-welt joint, ...	80	per cent.
3. Double-rivetted lap-joint, ...	72	„
4. Lap-welded joint, ...	66	„
5. Double-rivetted single-welt joint, ...	65	„
6. Single-rivetted lap-joint, ...	60	„

These percentages are to be accepted as for plates not more than ⅜ inch thick, with straight joints. But, with circular joints they, no doubt, hold good for all thicknesses; excepting that the welded lap-joint would bear a much higher ratio, and rank next to the welded scarf joint.

In round numbers, the working strengths of best boiler-plates are thus:—

Yorkshire plates, per square inch of entire section,			...	11,000 lbs.
Staffordshire plates,	do.	do.	...	9,000 „
American plates,	do.	do.	...	14,000 „
Do. (ordinary),	do.	do.	...	12,000 „
Cast-steel plates,	do.	do.	...	18,000 „

In round numbers, the working strengths of joints are thus:—

	Best Yorkshire.	Best Staffordshire.
1. Scarf-welded joint, per square inch of entire section, ...	11,000 lbs.	9,000 lbs.
2. Double-rivetted double-welt joint, ...	9,000 „	7,000 „
3. Double-rivetted lap-joint, ...	8,000 „	6,500 „
4. Lap-welded joint, ...	7,400 „	6,000 „
5. Double-rivetted single-welt joint, ...	7,300 „	6,000 „
6. Single-rivetted lap-joint, ...	6,700 „	5,400 „

It has been remarked, in a previous chapter, that the

inferior strength of the lap-welded joint, in the trials at Woolwich, probably arose from the shortness of the lap, about 1¼ inch, causing a very oblique strain upon the plate; and that, had the lap been extended to 2 or 3 inches, it would likely have ranged in strength next the scarf-weld. The strength assigned to the lap-weld must be accepted as provisional, and open to improvement.

CHAPTER V.

On the Strength of Stayed Surfaces, Tie-rods, Screwed Bolts, and Roof-stays.

There are round parts, and there are flat parts, in boilers. The former are self-sustaining in virtue of their circularity, the latter must be stayed to keep them in shape. In a locomotive-boiler, the flat parts are, the four sides or walls of the firebox, and their counterparts of the shell, the roof of the firebox, and the smokebox tube-plate. The surfaces which demand the most scrupulous and careful staying, are, the roof of the firebox, and the upper parts of the end plates of the boiler-shell. The resistance of flat plates to rupture should be somewhere in the ratio of the square of the thickness, and as the diameter or width inversely; and the resistance to flexure should be as the cube of the thickness, or inversely as the cube of the span, according to the ordinary laws of the strength and stiffness of materials. But,—not to specialize on this question,—the important consideration is, that the stiffness, or resistance to deflection, or elastic strength, of plates, increases in a very rapid ratio with the thickness, much more rapidly than the absolute strength or resistance to rupture; and that the thickness of flat plates is an important element in the question of stability of boilers—in the means of insuring rigidity, and an absolutely changeless form. A boiler may be abundantly strong, but insufficiently stiff; whereas, in a locomotive-boiler, above all others, identity of form is of great practical importance, as, besides the ordinary contingencies of over-strained joints and leakage, resulting from change of form, there are, unavoidably, connections and attachments to be made here and there, which can only be maintained in good order under superior conditions of stability of parts.

It becomes, therefore, necessary to stay the flat surfaces, independently of their intrinsic strength, by screwed and rivetted bolts for the walls of the firebox, girders for the roof, and tie-rods or gussets for the ends of the boiler.

Tensile Strength of Rods.—The strength of ordinary Staffordshire bar-iron is about 24 tons per square inch. According to the experiments of Colonel Kennedy, that of the best Staffordshire is about 28 tons per inch; Blaenavon cold-blast bar-iron bears 28 to 33 tons per inch; and Yorkshire bar-iron ("Leeds"), 30 to 31 tons per inch. These are the results of trials of round iron, fully 1⅛ inch diameter, having precisely 1 square inch of section; and it must be noted that the quantities are correct only for that particular diameter; for, as we shall afterwards find, in the testing of bolts and nuts, the proportional strength of bar-iron increases as the diameter is less. Lowmoor bars, best iron, are found by the Lowmoor Company to have the following ultimate strengths:—

1 inch diameter, 24⅜ tons, or 31 tons per square inch.
1¼ do. do. 34⅜ tons, or 28 tons do.

The 1¼-inch bar, having 56 per cent. more section, has but 40 per cent. more strength than the 1-inch bar; or, otherwise, per square inch of section, the 1¼-inch bar has 28 tons ultimate strength, and the 1-inch bar 31 tons. Hence much of the anomaly that arises in experimentalizing, when a bar is turned down to a smaller diameter, and thus only the core is tested for the measure of the strength of the whole bar. It is a general fact, that iron is improved in quality and tenacity by repeated rolling; and that thus smaller bars are stronger than larger bars:—wire, the extreme, being strongest of all, having 35 to 40 tons per square inch of ultimate strength. Rivet-iron has from 24 to 28 tons per square inch ultimate strength.

It may be concluded that the tensile strength of rods per inch of section varies materially with the diameter, being greater as the diameter is less: that is to say, the entire strength of the bolt does not increase so rapidly as the sectional area. Tie-rods used in boilers are usually about 1 inch diameter, varying from ⅞ inch to 1¼ inch; and, within these limits of size, the ultimate tensile strength of good Staffordshire bars is 25 tons per square inch; of best Staffordshire bars, 28 tons per inch; of best Yorkshire bars, 30 tons per inch. When screwed at the ends, within the original diameter, the strength is reduced by 2 tons per square inch, as shall subsequently be shown; and the reduced strengths of the rods are, respectively, 23 tons, 26 tons, and 28 tons per square inch of section. When the screw is formed upon a sufficiently enlarged diameter, the tensile strength of the bolt remains unimpaired.

Estimating the working strength of tie-rods at one-fifth of the ultimate strength, the Table No. III. contains the strengths of tie-rods of the diameters used in practice.

TABLE No. III.—OF THE ULTIMATE AND WORKING TENSILE STRENGTHS OF TIE-RODS.

Quality.	Diameter.	Tensile Strength. Ultimate Strength. Per Sq. Inch of Section.	Ultimate Strength. Whole Section.		Working Strength, taken at one-fifth of the Ultimate Strength.	
	Inches.	Tons.	Tons.	Lbs.	Tons.	Lbs.
Good Staffordshire, ...	⅞	25	15	33,700	3	6,700
	1		19·6	44,000	4	8,800
	1¼		25	56,000	5	11,200
Best Staffordshire, ...	⅞	28	16·8	37,700	3·4	7,500
	1		22	49,300	4·4	9,800
	1¼		28	62,700	5·6	12,500
Best Yorkshire, ...	⅞	30	18	40,400	3·6	8,100
	1		23·5	52,800	4·7	10,500
	1¼		30	67,200	6	13,400

Note.—The values in this Table are correct where the full section of the rod is maintained, in whatever way it is fixed. If screwed within the original diameter, one-tenth of the tabulated strength must be deducted.

In round numbers, the working strengths of a 1-inch tie-rod are—

Good Staffordshire, 1-inch rod, ... 9,000 lbs.
Best Staffordshire, do. .... 10,000 lbs.
Best Yorkshire, do. .... 10,500 lbs.

There is little difference between the last two named, and generally it may be said that the working strength of a 1-inch tie-rod of best iron is 10,000 lbs.

Influence of Temperature.—By Mr. Fairbairn's experiments, the strength of rivet-iron increases with the

temperature, from, say, 28 tons per inch, to 39 tons per inch, at 325°, continuing of undiminished strength up to 435°; at a red heat, the ultimate strength is only 16 tons per square inch.

Strength of Screwed Bolts and Nuts.—According to experiments made by Mr. Brunel, screwed bolts and nuts, of Coalbrookdale iron (Shropshire), 1¼ inch diameter, bore an average breaking weight, or tensile strain, of 29 tons, applied between the head and the nut, equivalent to 23·2 tons, or, say, 23 tons per square inch of section of the body of the bolt. Bolts and nuts of smaller diameter were found to increase in strength, per square inch of section, as the diameter was less. Thus,—

Diameter.	Breaking Weight.	Strain per Square Inch.
1¼ inch	29 tons	23 tons.
1⅛ „	21 „	21 „
1 „	20 „	25 „
⅞ „	15¼ „	25 „
¾ „	12 „	27 „
⅝ „	10¼ „	32 „

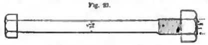
In most of these instances, the bolt snapped at the base of the screwed part, the bolt being 16 inches long between the head and the nut, as sketched, Fig. 22, and

Fig. 22.

the length of the screwed part 3½ inches. It is remarkable that the relative strength of the bolts increases as the size is reduced. Thus, ⅝-inch bolts, having only one-fourth of the sectional area of 1¼-inch bolts, are proved to have more than one-third the breaking weight; otherwise, the strength rises from 23 tons per inch of section for 1¼-inch bolts, to 32 tons per inch for ⅝-inch bolts. Here lies a new field of operation for experimentalists; meantime, we suppose we may hazard the explanation that the smaller rods are proportionally the stronger, for the same reason that bars are stronger than boiler-plates,—because they are more thoroughly rolled down.

That the screwing of a bolt should reduce its tensile strength, seems certain. How much? The bolts were not proved to show this; and an estimate can only be formed upon the results of four bolts, to sketch, Fig. 23, of

Fig. 23.



which the shank was 1¼ inch diameter, and the screwed part 1⅜ inch. The mean breaking weight was 31¼ tons, the bolts failing in the shank: equal to 25·2 tons per inch of section. Thus, the extra size of the screwed part added 2 tons per inch to the strength of the bolt; and, inversely, it may be inferred that the screwing of 1¼-inch bolts deducts 8 per cent. of the strength of the entire bolt. The deduction may amount to 10 or 12 per cent. for smaller bolts.

The heads of the 1¼-inch bolts were 1¼ inch thick, and stood fast during all the trials. The nuts of these bolts varied from 1¼ inch to ¾ inch in depth; at 1 inch deep, they stood well; at ⅞ inch, the threads were strained; and at ¾ inch, the thread was stripped from the bolt:—showing that the nut was rather shallow where its depth was three-fifths of the diameter. It is nevertheless established in ordinary practice, that the depth of the head of a bolt, and of the nut, is sufficient when it is half the diameter. Full and closely fitting threads are, of course, essential with such a proportion. In general, the thickness of the head may be half the diameter of the bolt; and that of the nut five-eighths of the diameter.

Screwed Stay-Bolts.—From experiments on the strength of screws let into boiler-plate and copper-plate, in the style of firebox stay-bolts, by Mr. Fairbairn, it was found, 1st, That a ¾-inch copper bolt, with an enlarged end, screwed into a ⅝-inch copper plate, and rivetted on the end, as in Fig. 24, broke with 7·2 tons tensile strain.

Fig. 24.

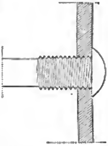
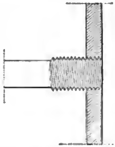


Fig. 25.



2d, That a ¾-inch iron bolt, screwed and rivetted into a ⅝-inch copper plate, failed with a load of 10·7 tons, the rivet-head being broken off, and the bolt drawn out of the plate, stripping the copper thread.

3d, That a ¾-inch iron bolt screwed, without rivetting, into a ⅝-inch copper plate, Fig. 25, was drawn out of the plate with 8·1 tons, stripping the copper thread.

4th, That a ¾-inch iron bolt, screwed and rivetted into a ⅝-inch iron plate, failed by fracture across the shank, with 12·5 tons, the screw and plate remaining uninjured. Shortly, these results exhibit as follows:—

1. Copper into copper, screwed and rivetted,			7·2 tons	breaking weight.
2. Iron into copper,	do.	do.	10·7	do.
3. Iron into copper, screwed only,			8·1	do.
4. Iron into iron, screwed and rivetted,			12·5	do.

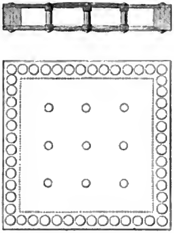
Touching the last of these results, iron into iron, the breaking weight is practically the same as that of the ¾-inch screwed bolts, tested by Mr. Brunel; the ⅝-inch depth of screw in the plate, supplemented by the rivetting, being sufficiently strong for the bolt, and equivalent to a nut ⅞ inch deep.

The first and second results, showing the strengths of copper and iron bolts screwed and rivetted into copper plates, are those which directly concern the question of firebox-stays—the iron stay being 50 per cent. stronger than the copper stay.

Firebox-stays have been tested still more directly, by Mr. Fairbairn. He constructed two flat boxes, 22 inches square, as sketched, Fig. 26, with top and bottom plates of ½-inch copper and ⅜-inch iron respectively, inclosing a 2½-inch water space, with 13/16-inch iron stays, having enlarged ends screwed and rivetted into the plates, to represent the conditions of an ordinary firebox. The first box had the stays placed as shown, at 5-inch intervals. On the application of water-pressure, the sides commenced to bulge out

or swell, between the stays, under 455 lbs. pressure per square inch; and, with 815 lbs. per inch, the box burst by drawing the head of one stay through the copper plate, as shown. In the second box, the stays were placed at

Fig. 26.



4-inch centres; the swelling commenced under 515 lbs. pressure, and amounted to one-third of an inch under 1600 lbs.; at 1625 lbs. per square inch, the box failed, by one of the stays drawing through the iron plate, stripping the thread in the plate. As each stay, in the first case, bore the pressure on an area of $5 \times 5 = 25$ square inches; and in the second, an area of $4 \times 4 = 16$ square inches; the total strains borne by the stays were, for the first, 815 lbs. × 25 inches = 9 tons on each stay; for the second, 1625 lbs. × 16 inches = 11¾ tons nearly on each stay. These strains are less than the tensile strength of the stays, which, according to Mr. Brunel's results, would be about 14 tons.

It appears that the grip of the stays is superior to the strength of the plates to resist bulging, even at 4-inch centres; that the tensile strength of the iron stay-bolt is at least equal to the grip in the plate; and that that of the copper bolt is less. In any case, the distortion of the plate is the first symptom of weakness. Thus:—

	Per square inch.
At 5-inch centres, distortion commenced at a pressure of	455 lbs.
At 4-inch do. do. do.	515 lbs.

Again, distributing the test-strengths of the bolts over surfaces of 5 inches and 4 inches square, they failed with the following pressures:—

		5-inch Surface.	4-inch Surface.
1. Copper into copper, screwed and rivetted.	per square inch,	645 lbs.	1008 lbs.
2. Iron into copper, screwed and rivetted.	do.	959 lbs.	1498 lbs.
3. Iron into copper, screwed only,..........	do.	726 lbs.	1134 lbs.
4. Iron into iron, screwed and rivetted,............	do.	1120 lbs.	1749 lbs.

Note.—Diameter of bolts, ¾ inch, clear of thread.

The total working strengths of copper and iron bolts, ¾ inch diameter at the base of the thread, screwed and rivetted into ½-inch copper plates, taken at one-fifth of the rupturing strain, are, for copper bolts, 3200 lbs., and for iron bolts, 4800 lbs. For ¾-inch iron bolts, in ⅜-inch iron plates, 5600 lbs.

Firebox Roof-Stays.—These consist of wrought iron flat bars, on edge, singly or in couples, extending between the front and back plates of the firebox, with bolts let down through them at equal intervals, or screwed in from beneath, to sustain the roof of the firebox. Mr. Edwin Clark found, in testing wrought iron bars for their transverse strength, that the deflection became excessive long before the bars broke, and that, practically, bars should be tested transversely, not for strength, but for stiffness. He found that, by previously straining and straightening a wrought iron bar, its stiffness and practical strength are greatly increased.*

According to an account of experimental tests of firebox roof-stays, recently published by the Board of Trade, it appears that a stay made of two plates, ½ inch thick, 5 inches deep, placed 1 inch apart, rivetted together by ¾-inch rivets, and made to span a firebox 3 feet 6 inches long, bore a load of 10¾ tons at the centre, the deflection under which was not mentioned, but it acquired a permanent set of ¼ inch. The lower rivet-holes were barely 1 inch clear of the lower edges of the stay, and deducted, probably, one-third from the strength of the solid bar. Allowing, then, one-half more than the testing load, we estimate that the strength of the stay, had it been solid—composed of two entire bars 5 × ½ inch—would have been equal to a load of 13 tons at the centre. By Mr. E. Clark's formula, the working strength of a stay 42 inches long, consisting of two solid plates 5 inches by ½ inch, would be—

$$\frac{5 \times 1 \times 5}{42} \times 15{\cdot}3 = 9{\cdot}1 \text{ tons},$$

which is only about two-thirds of the strength, estimated directly from experiment. Another stay, similarly made, of two ½-inch plates, rivetted together, but reduced to 3½ inches deep at the middle, was tested in the same way,

* "If a new bar, 1½ inch square, with 3-feet bearings, were used as a beam when no greater deflection than 8-10ths of an inch could be allowed, the greatest load such a bar would bear would be 28·7 cwts.; but the bar, previously strained, would require 42 cwts. to deflect it the same amount, while with this weight the new bar would be bent upwards of 5 inches. The strained bar would, therefore, under such conditions, be 46 per cent. stronger than the new bar; and, as the weight increases, the increase of strength becomes still more remarkable. In fact, as regards deflection, the strained beam may be considered a new material, of which the elasticity is quite different from that of the original beam; and this important change in the practical value of the new bars is obtained without difficulty or expense. The ultimate strength of a 3-feet bar of cast-iron, 1½ inch square, would be 25·5 cwts., and the ultimate deflection ·29 inch; and with this same deflection the new bar would only bear 24 cwts., and the strained bar 28·8 cwts. If we derive constants from the formula, $s = \frac{l\,w}{a\,d}$, assuming the above to be the greatest deflection that can be admitted, we have, for the new bar,

$$w = \frac{a\,d}{l}\,15{\cdot}3 \text{ tons};$$

for the strained bar,

$$w = \frac{a\,d}{l}\,22{\cdot}3 \text{ tons};$$

all the dimensions being in inches." In these formulas, w is the maximum useful load at the centre of the bar, a is the sectional area at the middle, d the depth there, and l the span.—*Britannia and Conway Tubular Bridges*, page 451.

and broke across, under a load of 7½ tons at the centre. By the formula, the working strength of this stay would have been 3·85 tons at the centre, or one-half the breaking strength. But in this it is assumed that there was no reduction of strength by rivets near the middle of its length.

In connection with the same subject, it is reported that a boiler was tested by water-pressure, in which roof-stays of the same construction were applied to a firebox 42 inches long, fastened to the roof in the usual way, by bolts at short intervals, there being a clear space of 1 inch or so between the roof-plate and the stay, except at the bolts, and the plate being, say ½ inch thick. The stays were placed at intervals of 5 inches between centres. The two central stays were only 3½ inches deep. The boiler was proved by water-pressure; at 469 lbs. per square inch, four of the roof-stays failed—the two central stays and the stay next to each; they cracked across the lower half of each stay, and deflected 1⅞ inch for the central stays, and 1⅝ inch for the two others. The failure was accompanied by two successive reports at a few seconds' interval, indicating that the central stays failed first, then the others. The total pressure borne by each stay previous to failure, acted on an area of 42 × 5 inches = 210 square inches, and amounted to 210 × 469 lbs. = 98,490 lbs., or 44 tons, uniformly distributed, or 22 tons at the centre. This, then, should be accepted as the ultimate strength of the two central stays, in their connection with the firebox. Stays of the same dimensions, proved separately, bore only 7½ tons of breaking weight—just one-third of the breaking strength when fixed to the firebox. To account for this striking difference, without reference to the absolute value of the tests, it may be suggested that the roof-plate of the firebox, being intimately united to the stay, became a part of it, and bore its share of the strain tensilely, as a lower flange. There was, in fact, for each stay, a lower flange of copper, 5 inches broad, ½ inch thick, presenting 2½ square inches of section, fixed, moreover, at the extremities. It would be idle to speculate on the precise amount of strength thus added, or on the amount of lateral support derived from the neighbouring stays, in the absence of necessary particulars; but, at least, it is apparent, that an important accession of strength is gained to a roof-stay by intimately uniting it to the roof-plate. The strength of the smaller stays, then, presents itself thus:—

Tested alone, failed with........................	7½	tons on the centre.	
Tested in its place, failed with..............	22	do.	do.
Working strength, by formula, treating it as a solid plate, unaffected by rivet-holes,..	3·85	do.	do.

Again, the strength of the larger stay appears thus:—

Tested alone, acquired a permanent set of ⅛ inch, with..............................	10¾	tons on the centre.	
Corresponding strength of solid stay alone, as unaffected by rivet-holes, estimated from the test,..................	13	do.	do.
Tested in its place, failed after the smaller stays gave way, and bore at least,..	22	do.	do.
Working strength, by formula, treating it as a solid plate,....................	13	do.	do.

As to the smaller stay, it appears that, in its place, its ultimate strength was between five and six times the working strength assigned to it by the formula, treating it as a solid plate; and the larger stay bore, in its place, at least two-thirds more than the working strength as by formula. It must have borne much more than that proportion, had it been placed beside stays of equal strength. Upon the whole, therefore, we are disposed to recommend Mr. E. Clark's formula for the transverse strength of iron bars, as applied to the roofs of fireboxes, and fixed in the ordinary manner. It may be remarked that, inasmuch as the absolute strength varies only as the square of the depth, and as the length inversely; and the stiffness varies as the cube of the depth, and inversely as the cube of the length, the proportion of deflection to span cannot be the same in all cases. Should it be found, in practice generally, that there is an increase of strength by straining and straightening iron bars, already mentioned on Mr. E. Clark's authority, the process may, of course, be beneficially applied to strengthen roof-stay bars.

Gusset-Stays.—These stays are applied in the angles of the firebox shell, to stay the flat surfaces, front and back, to the cylindrical portions; superseding the more ordinary thorough tie-rods, which they do effectually. They may be most solidly and simply welded into their places by Bertram's process, of which there are excellent examples.

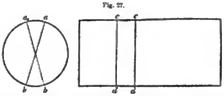
CHAPTER VI.

Construction of the Boiler.—General Principles, Rules, and Data.

In the shell of the boiler the strongest iron should be used, for the parts subject to steam-pressure, and the plates should be put together in the strongest manner, with the strongest joints. The occurrence of boiler explosions on railways, shows that we occasionally, in our efforts to concentrate power, overstrain the powers of boilers; and though, generally, the failures by explosion have occurred with old boilers, which are of course considerably surpassed in strength by those of more recent construction, yet they have made a beginning, in our railway experience,—that is a fact; and the question of the strength of boilers should now be one of sufficiency simply, irrespective of cost.

But the strongest joints, also, should be used, where the greatest resistance is required. Regarding the locomotive-boiler as a cylinder with flat ends, the greatest strain falls necessarily upon the longitudinal seams, and the least upon the transverse circular seams at and betwixt the ends of the boiler. The distinction may be concisely illustrated thus:—Let the circle, Fig. 27, be a cross section of a boiler, then the area of the circle is a

Fig. 27.



measure of the longitudinal pressure, exerted by the steam upon the end of the boiler, to be resisted by the transverse joints. Again, let the parallelogram, Fig. 27, be a

longitudinal section of the boiler, then the area of the figure is a measure of the transverse pressure of the steam, to be borne by the longitudinal joints. To find the proportional strains upon equal sections of the circular and longitudinal joints, set off the interval *a a* upon the circular seam, and an equal interval *c c* upon the longitudinal seam; draw the diameters *a b*, *a b*, and the parallels *c d*, *c d*; then the areas of pressure to be resisted in the two cases, are, for the circular seams, the two triangular spaces *a b*; and, for the longitudinal seams, the rectangle, *c d*. The united areas of the two triangles are obviously but one-half of the area of the rectangle, and therefore the total steam-pressure to be resisted by the two lengths of circular joint, *a a*, *b b*, is only half of that to be borne by the two equal lengths *c c*, *d d*. The same proportion holds good, all round the circle; and it follows, generally, that the strain per unit of length, on transverse circular joints, is only half of that upon longitudinal joints.

The longitudinal seams, therefore, should be the strongest, and there, setting aside meantime the welded joint, the double-welt double-rivetted joint, should be applied; and for the circular seams, bearing only half the strain upon the others, the single-rivetted lap-joint is sufficient, being, in fact, proportionally stronger in its place than the other;—proportionally stronger, that is to say, with respect to strains arising from steam-pressure; and when, as it ought to be, the boiler is employed exclusively as a generator of steam, and is placed freely on the frame. But, where it is rigidly bound to the frames, or employed as a responsible fastening for the steam-cylinders, which it ought not to be, double-rivetted joints had better, no doubt, be employed to resist the extra strains thus incurred, at the junctions of the barrel with the firebox-shell and the smoke-box.

The working strength of the double-welt double-rivetted joint was found to be 9000 lbs. per square inch of section, for best Lowmoor plate; and, with that joint applied to the longitudinal seams, the boiler becomes qualified to work under a maximum strain of 9000 lbs. per square inch of section. The distinction here recognized, is of practical importance:—the tensile strength transversely of the cylindrical elements of the boiler, is the measure of its strength, because the longitudinal seams of the cylindrical parts are strained twice as much as the other seams; and a boiler united by double-welt double-rivetted longitudinal joints in the cylindrical portions, and everywhere else by single-rivet lap-joints, is practically of equal strength throughout.

Take an example: A boiler is 48 inches in diameter, of $\frac{3}{8}$-inch plate, with 120 lbs. steam:—to find the strain on the metal. The two sides are, together, $\frac{3}{4}$ inch thick, and one square inch of section is developed in a length of $1 + \frac{1}{3} = 1\frac{1}{3}$ inch, measured along the boiler; because, inversely, $\frac{3}{4} \times 1\frac{1}{3} = 1$ square inch. Now, $48 \times 1\frac{1}{3} = 64$ square inches, the diametrical area of pressure (which is represented by the rectangle *c d*, in Fig. 27, recently considered), sustained by the square inch section of metal; and $64 \times 120 = 7680$ lbs. per square inch, is the strain of the steam-pressure on the longitudinal section. The longitudinal strain per square inch of transverse section, due to the pressure on the entire end of the boiler, would be, as already shown, half of the transverse strain; that is, $7680 \div 2 = 3840$ lbs. per square inch. It may be otherwise proved arithmetically:—48 inches diameter yields a circumference of 151 inches, and an area of 1809·5 square inches, and $1809{\cdot}5 \times 120 = 217{,}140$ lbs. total pressure on the end; to bear this pressure, there is 151 inches circumference of $\frac{3}{8}$-inch plate, equal in area to 56·6 square inches, and $217{,}140 \div 56{\cdot}6 = 3840$ lbs., the longitudinal strain per square inch of transverse section of the boiler, as already found.

At the maximum working strain, 9000 lbs. per square inch of longitudinal section of metal, the longitudinal strain is 4500 lbs. per square inch of transverse section, which may be abundantly provided for by single-rivet lap-joints; and the steam-pressure due to this strain, would amount to $9000 \div 64 = 140$ lbs. per square inch of surface.

As a matter of fact, the ends of locomotive-boilers are not so exposed as has just been assumed for illustration. For the tubes not only subtract by as much as their total sectional area, from the smoke-box end, but they are in themselves very efficient stays,—obviously so, for they entirely support the upper part of the firebox-tubeplate. The greater part of the back end of the boiler, also, is stayed to the firebox, and they are mutually supporting. There are, in short, only the upper segments of the end-plates requiring extra stays; and the question is, then, simply, whether they should be stayed by thorough tie-rods or by gussets? and that is a matter of convenience.

For example, in a 48-inch boiler, the circular segment above the tubes, may be, say, 20 inches high, and may be effectually guarded by a few 1-inch tie-rods, at 6 to 8 inches apart. If each rod be charged with the pressure of 120 lbs. steam, on a surface averaging 7 inches square, the total would be about 6000 lbs.; opposed to this, an inch bar of best iron has a working strength of 10,000 lbs., equal to upwards of 200 lbs. per square inch. A few gussets converging from the circumference, at suitable intervals, answer precisely the same purpose.

Rules for the Strength of Locomotive-Boilers.—From the data already supplied, rules may be constructed for the strength of the different parts of boilers,—the cylindrical parts, and the flat parts.

Rules for the Strength of the Cylindrical Parts of Boilers.

RULE I. *To find the Working Steam-Pressure due to a given diameter, thickness of plate, and quality of joint.* Multiply the thickness of plate in inches by 2,—and by the working strength of the longitudinal joint in lbs. per square inch;—and divide by the diameter in inches. The quotient is the working steam-pressure in lbs. per square inch.

RULE II. *To find the Thickness of Plate due to a given diameter, quality of joint, and working pressure.*—Multiply the working pressure in lbs. per square inch by the diameter in inches;—and divide the product by the working strength of the longitudinal joint in lbs.,—and by 2. The final quotient is the required thickness of plate in inches.

Note 1. These rules are applicable to every kind of joint, when the thickness of plate does not exceed $\frac{5}{8}$ inch; and they apply to any thickness of plate, when the joint is scarf-welded, or double-rivetted with double welts.

2. The following tablet of working strengths of joints is appended for convenient reference:—

Joint.	Best Yorkshire.	Best Staffordshire.
	lbs.	lbs.
Scarf-welded, ...	11,000	9,000
Double-rivetted double-welt,..................	9,000	7,000
Double-rivetted lap, ...	8,000	6,500
Lap-welded, ...	7,400	6,000
Double-rivetted single-welt,..................	7,300	6,000
Single-rivetted lap, ...	6,700	5,400

3. The ultimate or bursting pressure is five times the working pressure.

4. The rules are applicable also to cast-steel boilers, which have twice the strength of best Staffordshire iron boilers.

Example.—Take, as before, a boiler of best Yorkshire plate, 48 inches diameter, of $\frac{3}{8}$-inch plate, and with double-welt longitudinal joints; to find the working pressure The working strength of the joint is 9000 lbs. per inch, and, by Rule I., the maximum working pressure is

$$\frac{\frac{3}{8} \times 2 \times 9000}{48} = 140 \text{ lbs. per square inch.}$$

Conversely, to find the thickness of plate, for a diameter of 48 inches, with a double-welt joint, and 140 lbs. per square inch, working pressure. By Rule II.,

$$\frac{140 \times 48}{9000 \times 2} = \frac{3}{8} \text{ inch, the required thickness of plate.}$$

Rules for the Strength of the Flat Parts of Boilers:—

The estimation of the strength of flat parts is based on the strength of the stays, no credit being taken for the inherent strength of the plate itself. Stays are arranged usually at regular intervals, dividing the surface into segments, which may be reckoned at the rate of one segment per stay. The firebox stay-bolts are pitched in squares or rectangles.

RULE III. *To find the Working Steam-Pressure due to a given diameter of tie-rod, and area of segment to be guarded by it.* Divide the working strength of the tie-rod in lbs., by the area of segment in square inches. The quotient is the working steam-pressure in lbs. per square inch.

RULE IV. *To find the Area of Segment due to a given diameter of tie-rod and working pressure.* Divide the working strength of the tie-rod in lbs., by the working pressure in lbs. per square inch. The quotient is the area of segment in square inches.

Note 1. The following are the working tensile strengths of best iron rods, in round numbers:—

$\frac{3}{4}$ inch diameter,	....	8,000 lbs.
1 do. do.,	....	10,000 lbs.
$1\frac{1}{4}$ do. do.,	....	13,000 lbs.

2. The full section of the rod is assumed to be retained. If the rod be reduced in section by screwing, 10 per cent. is deducted from the working strength.

RULE V. *To find the Working Pressure due to a given pitch of stay-bolt, screwed and rivetted into the plates, the solid diameter of bolt being $\frac{3}{4}$ inch.* Divide the working strength of the stay-bolt in lbs., by the square of the pitch in inches. The quotient is the working pressure in lbs. per square inch.

RULE VI. *To find the Pitch of Stay-bolts, due to a given working pressure.* Divide the working strength of the stay-bolt in lbs., by the working pressure in lbs. per square inch,—and find the square root of the quotient. The result is the pitch in inches.

Note 1. The following are the working strengths of stay-bolts $\frac{3}{4}$ inch solid diameter, screwed and rivetted into plates:—

Copper stay-bolt in copper plate,			....	3,200 lbs.
Iron	do.	do.	do.	4,800 lbs.
Iron	do.	in iron plate,	....	5,600 lbs.

2. When the bolts are pitched in rectangles, the product of the horizontal and vertical pitches is to be taken, in Rule V., instead of the square of the pitch; and, conversely, in Rule VI., the result is the mean pitch.

3. The working strength probably increases with the diameter of the bolt.

4. The working strength cannot be materially affected by the thickness of plate in practice.

Example 1. An iron bolt is screwed and rivetted into an iron plate, at 4 inches horizontal, and 5 inches vertical pitch; what is the working pressure? The working strength is 5600 lbs., and by Rule V.,

$$\frac{5600}{4 \times 5} = 280 \text{ lbs. per square inch, the working pressure.}$$

If the pitch be $4\frac{1}{2}$ inches both ways, then

$$\frac{5600}{4 \cdot 5^2} = 276 \text{ lbs. per square inch, the working pressure.}$$

Example 2. The working pressure is 200 lbs. per square inch; required the pitch of copper bolts in copper plates. The working strength is 3200 lbs., and

$$\frac{3200}{200} = 16, \text{ and } \sqrt{16} = 4 \text{ inches, the pitch;}$$

and the bolts may be otherwise pitched, at $3\frac{1}{2}$ inches one way, and $4\frac{1}{2}$ inches the other.

Roof-Stays of the Firebox.—The load to be sustained by roof-stays, individually, or more properly that which is assigned to them, is readily estimated by dividing the area of the roof by the number of stays, and multiplying the aliquot part thus rendered by the steam-pressure. The walls of the firebox sustain directly part of the pressure on the roof, without the intervention of the stays; and, therefore, in assigning the whole of the pressure to the roof-stays, there is an excess of allowance on the safe side. Stays are pitched at equal intervals apart, and the area of roof guarded by each stay is measured by the length of roof or span, into the pitch. From these considerations, and from those already suggested by the application of Mr. E. Clark's formula to roof-stays, the following rules as to roof-stays are derived:—

RULE VII. *To find the Pressure borne by the roof-stays of a firebox.* Multiply the span of the roof in inches, by the pitch of the stays in inches,—and by the pressure in lbs. per square inch;—and divide by 2240. The product is the pressure uniformly distributed, borne by each roof-stay, in tons.

RULE VIII. *To find the Working Strength of a roof-stay of given dimensions, fixed in its place.* Multiply the thickness of the stay at the centre, in inches, by the square of its depth at the centre, in inches,—and by 30;—and divide the product by the length of span in inches. The quotient is the working load, equally distributed, in tons, when the stay is fixed in its place.

Example.—Mr. D. Gooch's tank-locomotive, working with 120 lbs. pressure, has the roof-stays of the firebox, $6\frac{1}{2}$ inches deep, by 1 inch thick, at the centre, with 50 inches

span, and at 5 inches pitch. First, what is the load sustained by each roof-stay? By Rule VII.,

$$\frac{50 \times 5 \times 120}{2240} = 13{\cdot}4 \text{ tons, the load on one stay.}$$

Second, what is the working strength of one stay? By Rule VIII.,

$$\frac{1 \times 6{\cdot}5^2 \times 30}{50} = 25{\cdot}3 \text{ tons, the working strength,}$$

or load which the stay is capable of bearing,—nearly double the actual load imposed by the working steam-pressure. To resolve the working strength into steam-pressure, the area of roof guarded by one stay is $50 \times 5 = 250$ square inches, and

$$\frac{25{\cdot}3 \times 2240}{250} = 227 \text{ lbs. pressure per square inch,}$$

the pressure of steam equivalent to the working strength of the roof-stays.

The Table No. IV., of the working pressures of boilers, may be useful for consultation. It is constructed with the aid of Rule I.

TABLE No. IV.—OF THE WORKING PRESSURE OF LOCOMOTIVE-BOILERS, MADE OF BEST YORKSHIRE PLATES.

Inside Diameter.	Thickness of Plate.	Working Pressures, for different kinds of Longitudinal Joints. Welded Joints. Scarf-Weld.	Lap-Weld.	Rivetted Joints. Double-Rivetted Double-Weld.	Double-Rivetted Lap.	Single-Rivetted Lap.
inches.	inches.	lbs. per square inch.	lbs. per square inch.	lbs. per square inch.	lbs. per square inch.	lbs. per square inch.
30	$\frac{1}{4}$	183	123	150	133	112
	$\frac{5}{16}$	229	155	188	167	139
	$\frac{3}{8}$	275	187	225	200	167
	$\frac{7}{16}$	321	...	262	...	...
	$\frac{1}{2}$	367	...	300	...	...
33	$\frac{1}{4}$	167	112	136	121	102
	$\frac{5}{16}$	208	140	170	151	127
	$\frac{3}{8}$	250	168	204	182	152
	$\frac{7}{16}$	292	...	238	...	...
	$\frac{1}{2}$	333	...	273	...	...
36	$\frac{1}{4}$	153	103	125	111	93
	$\frac{5}{16}$	191	128	156	139	116
	$\frac{3}{8}$	229	154	187	167	139
	$\frac{7}{16}$	267	...	217	...	...
	$\frac{1}{2}$	305	...	250	...	...
39	$\frac{1}{4}$	141	95	116	102	86
	$\frac{5}{16}$	176	119	145	128	108
	$\frac{3}{8}$	212	143	174	154	129
	$\frac{7}{16}$	247	...	203	...	...
	$\frac{1}{2}$	282	...	231	...	...
42	$\frac{1}{4}$	131	88	107	95	80
	$\frac{5}{16}$	164	110	134	119	100
	$\frac{3}{8}$	197	132	161	143	120
	$\frac{7}{16}$	230	...	189	...	...
	$\frac{1}{2}$	262	...	214	...	...
45	$\frac{1}{4}$	122	82	100	89	75
	$\frac{5}{16}$	153	103	125	111	94
	$\frac{3}{8}$	183	123	150	133	112
	$\frac{7}{16}$	214	...	175	...	...
	$\frac{1}{2}$	244	...	200	...	...
48	$\frac{1}{4}$	115	77	94	83	70
	$\frac{5}{16}$	144	96	117	104	88
	$\frac{3}{8}$	173	115	141	125	106
	$\frac{7}{16}$	203	...	164	...	...
	$\frac{1}{2}$	229	...	188	...	...
51	$\frac{1}{4}$	108	72	88	78	66
	$\frac{5}{16}$	135	91	110	98	82
	$\frac{3}{8}$	162	109	132	117	98
	$\frac{7}{16}$	189	...	154	...	...
	$\frac{1}{2}$	216	...	176	...	...
54	$\frac{1}{4}$	102	68	83	74	62
	$\frac{5}{16}$	127	86	104	92	77
	$\frac{3}{8}$	153	103	125	111	92
	$\frac{7}{16}$	178	...	146	...	...
	$\frac{1}{2}$	204	...	167	...	...

TABLE No. IV.—Continued.

Inside Diameter.	Thickness of Plate.	Working Pressures, for different kinds of Longitudinal Joints. Welded Joints. Scarf-Weld.	Lap-Weld.	Rivetted Joints. Double-Rivetted Double-Weld.	Double-Rivetted Lap.	Single-Rivetted Lap.
inches.	inches.	lbs. per square inch.	lbs. per square inch.	lbs. per square inch.	lbs. per square inch.	lbs. per square inch.
57	$\frac{1}{4}$	96	65	79	70	59
	$\frac{5}{16}$	120	81	99	88	74
	$\frac{3}{8}$	145	97	119	106	89
	$\frac{7}{16}$	169	...	139	...	...
	$\frac{1}{2}$	193	...	158	...	...
60	$\frac{1}{4}$	92	62	75	67	56
	$\frac{5}{16}$	114	77	94	83	70
	$\frac{3}{8}$	138	92	113	100	84
	$\frac{7}{16}$	161	...	133	...	...
	$\frac{1}{2}$	183	...	150	...	...

Note 1. The blanks respecting the $\frac{7}{16}$-inch and $\frac{1}{2}$-inch plates, denote that the pressures are uncertain, but may be assumed at least equal to those for $\frac{3}{8}$-inch plates.

2. The working pressures for $\frac{1}{4}$-inch and $\frac{5}{16}$-inch plates, are estimated in the ratio of the thickness from those for $\frac{3}{8}$-inch plates.

3. The BURSTING PRESSURE is five times the working pressure.

4. To find the working pressures of boilers made of other metals undernamed, multiply the pressures given in the Table by the annexed multipliers:—

Best Staffordshire plate, ... ·82
(or, roundly, deduct one-fifth.)
Best American plate, ... 1·27
(or, roundly, add one-fourth.)
Ordinary American plate, ... 1·10
(or, roundly, add one-tenth.)
Cast-steel plate, ... 1·64
(or, roundly, add two-thirds.)

CHAPTER VII.

CONSTRUCTION OF THE BOILER.—DETAILS.

Rivet-joints.—Rivets are usually $\frac{3}{4}$ inch diameter, and pitched at $1\frac{3}{4}$ inch centres; occasionally $\frac{7}{8}$ inch diameter. But, according to the trials, the practice therein detailed is superior:—$\frac{7}{8}$-inch rivets, at 2 inches pitch, for $\frac{5}{8}$ and $\frac{1}{2}$ inch plates; in these trials, the rivets were found to be as strong as the plates. For thinner boiler-plates, a shorter pitch of $1\frac{5}{8}$ inch, with $\frac{3}{4}$-inch rivets, or $1\frac{1}{2}$-inch pitch with $\frac{11}{16}$-inch rivets, is advisable, to supply the necessity, not of strength, but of tightness, as remarked by Mr. Fairbairn. Punched rivet-holes are as good as, indeed better than drilled holes, in good metal, as the punched hole is conical, and by applying the small ends together, in the lap-joint, as in Fig. 28, the rivet becomes a double-cone, converging the lines of strain through the plates, shortening the leverage, and in so far stiffening the joint.

Fig. 28.

Fig. 29.

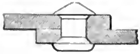
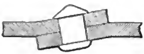


Fig. 30.



It is known that a slight countersinking of the rivet-holes, as done by Beyer & Co., Fig. 29. improves the joint,

on the same principle. Mr. D. Gooch anticipates the twisting of the single-rivet joint, and shapes it originally, as in Fig. 30, so as to have less liability to distortion; this is good. Long rivets are bad, and extra workmanship may be judiciously incurred to avoid them. At the junction of the firebox and the shell at the doorway, long rivets are common, and frequently troublesome by leaking. To retain the advantage of the full uncontracted water-space there, Mr. Beattie constructs a ring of boiler-plate, Fig. 31, flanged and rivetted to the firebox, and separately rivetted to the shell with angle-iron,—having short rivets throughout. Mr. Beattie also forms the junction of the firebox and the combustion-chamber of his coal-burning engines, as in Fig. 32, with a ring wrought out of plate-iron with two flanges, of which one is rivetted to the firebox, and the other, for want of access for rivets, is joined to the combustion-chamber by screws. For the same reason, Hackworth's junction at the bottom of the firebox, Fig. 33, with a piece of boiler-plate doubled, and separate rivetting, is a better job than that made with a solid bar, as usual. These forms of junction are advantageous, also, in minimizing the obstruction to the circulation of water and steam.

Fig. 31

Fig. 32

Fig. 33

In the seams of the firebox, double-rivetting is inexpedient, as the long lap thus required, is liable to burn off, and the rivet-heads with it. On the score of strength, also, it seems unnecessary, for the firebox is so thoroughly stayed as to admit of very little tensile strain being thrown upon the joint. Mr. Dewrance found that the heads of stay-bolts, made with square heads, projecting 2½ inches into the firebox, burned down to a projection of 1¼ inch, at which point they remained.

Furrowing of boilers at the joints.—Probably the most important practical inference to be drawn from the tests of the strength of rivetted joints, is the explanation they supply of the failure, hitherto unexplained, of boiler-plates, not at the joints, but in their neighbourhood. We are aware that electrical and galvanic action are freely adduced in explanation. But these words have two meanings:—they mean electricity and galvanism; and they mean ignorance and mystery. It is known that boilers fail by corrosive and other agencies eating into the plates, on the inside, pitting and furrowing the surface. The pitting of the metal is readily explained by the presence of chemical agents in solution in the water, and the known inequality of substance of iron plates and bars, in consequence of which the metal is gradually but unequally separated and dissolved; and probably a weak galvanic circuit may be established between the iron shell and the brass tubes, accelerating the process of dissolution. But this explanation does not meet the frequent case of a straight continuous furrow, cut like a groove upon the surface. Furrows are observed to be formed parallel to, and close to the rivetted joints. Not in any case that we are aware of, have they been found at any notable distance from a rivetted joint, nor otherwise than parallel to one. The inference is inevitable, that there is a relationship betwixt them: and our conviction is, that the alternate tension and relaxation of the plates at the joints, as the steam is got up and let down, are attended by an alternate distortion, incipient it may be, and resumption of the normal form, a bending and unbending of the plates on each side of the joint; in consequence of which the texture of the metal is gradually loosened, in lines near to, and parallel to the joint, and it is thus laid open to corrosive action. On this interpretation, the commencement of a groove or furrow, establishing a weak place, and concentrating the action there, would suffice to extend and deepen it, to the dangerous limits occasionally announced by explosions.

The weakness attendant on lap-joints is strikingly exemplified in the lap-welded joint, when subjected to extreme tension; the tensile strength, though the metal at the weld is perfectly solid and fully as strong in itself as the body of the plate, is much below that due to the regular section of the plate. Here, there is no elementary weakness in the reduction of metal by rivet-holes; the inferiority of strength arises solely from the bending of the plates on both sides of the lap, and the overstraining of the firebox, in the endeavour to attain to the position of stability.

Mr. John Sewell, commenting on the corrosion of locomotive-boilers, ascribes the furrowing of plates at rivet-joints, to the interruption of the vibrations of the boiler by these joints, the localization of the fatigue at these places, and the increased susceptibility, in consequence, to corrosive action.* This action has, doubtless, a tendency to aggravate the evil of lap-jointing; but we are disposed to ascribe the evil to the lateral bending and unbending of the plates as the primary cause.

The furrowing of lap-jointed plates reads an important lesson on the real and intimately practical value of direct connection and direct action, in exerting, transmitting, or resisting forces.

That the furrowing of plates at the rivetted joints results from the indirectness of the strain of the steam-pressure, is rendered still more probable by the analogous furrowing which results from reciprocating strains of another kind. In the more ancient classes of engines, in which the cylinders are fixed to and work from the smoke-box plates, the alternate forward and backward strains by the steam-pressure on the piston, have been observed to weaken and to subject to corrosion and leakage, the substance of the plate along the edge of the angle-iron at the junction with the barrel. In further corroboration of this doctrine, Mr. Colburn states that he is not aware that any accidents from furrowing of boiler-plates have

* "As rivetted joints destroy the elastic homogeneousness of the boiler, the waves of expansion, contraction, and vibration, are arrested there by the greater rigidity of the rivetted double thickness of metal, which tends to localize the fatigue sustained by the iron near these points, and it also appears to increase the susceptibility to corrosive action, since the furrows generally take the line of that fatigue, and are often deeper than the spots on the plates."—*Report of the Board of Trade on Railway Accidents*, 1855, page 49.

taken place in the United States; and we believe that their immunity from accidents arising from this source, is to be ascribed to the use of very thin boiler-plates, $\frac{1}{4}$ to $\frac{5}{16}$ inch thick.

Firebox Roof-stays.—The perfect fitting of the roof-stays to the superficies of the firebox, is of essential importance; not only at the intermediate points of contact, where the holding bolts are applied, but particularly at the ends, so as to direct the pressure vertically upon the front and back walls of the firebox. Proper and well-spread fitting is the more needful at the ends, as the resisting power of the copper of the firebox to compression is very low,—only 3 tons per square inch, according to Mr. Fairbairn; whereas, a roof-stay carrying 12 tons of pressure, throws 6 tons upon each end, for which a well-spread bearing is essential. An ordinary roof-stay, 1 inch thick, with a bearing at the ends 2 inches long, has 2 square inches of bearing surface, which, to carry 6 tons, must support a load of 3 tons per square inch, up to the limits of resistance to compression. Fairbairn judiciously spreads the end of the roof-stays, increasing the bearing to about 5 square inches at each end; others, desirous apparently of clearing the rivet-joint, bear only upon the extreme corner of the vertical plate. It appears to us that additional provision should be made to extend the bearing of the ends of roof-stays, beyond what is generally provided, considering the want of firmness of copper plate.

The method of flanging the front and back plates, and lapping them under the roof-plate, affords probably the strongest junction for resistance to pressure, when the roof-stays are accurately fitted to, and made to bear upon, and embrace the upright plates. It is otherwise if they are not so; and the American practice of placing the roof-stays transversely, causing their ends to bear directly upon the edges of the side plates, brought up square on the outside for the purpose, possesses the advantages of a direct and square bearing, of relieving the tube-plate of the downward pressure, and of adjusting the span of the stays to the width of the firebox, instead of its length. It is likely that the stress of roof-stays landed on the tube-plate, has occasionally been a cause of leakage of tubes, and of failure of the tube-plate; the side plates are better adapted to bear the pressure, as the stay-bolts in the sides are more numerous and shorter than in the tube-plate. Transverse stays would obstruct the insertion of longitudinal tie-rods, except above their level; but gussets could be inserted to stay the ends of the boiler. Applied transversely, the roof-stays could be extended to the sides of the firebox-shell, and rivetted to them, thereby entirely relieving the side stay-bolts from downward strains; further, they would stiffen the sides of the boiler, and their strength as girders would be doubled, bearing the same relation to ordinary roof-stays, that a beam fixed at both ends bears to a beam laid upon props. On this plan, explosions of the firebox would be practically impossible. On the ordinary plan, the linking of the three or four central roof-stays, or, say, half the number, to the crown of the shell, is of great utility in strengthening the boiler: the central roof-stays are the most in need of such aid, for, as was shown in the test by water-pressure, already quoted, out of eight roof-stays, the four in the middle were the first and only ones to give way.

In the design of roof-stays, they should, of course, be equally strong throughout their length. The best plan is to form each stay of two plain flat plates, studded and rivetted together, sufficiently apart to permit the holding-down bolts between them.

Side Stay-bolts.—It remains a question, whether iron or copper is the best material for stay-bolts. It is not a question of strength, for copper is abundantly strong enough, though iron is ultimately stronger; but, unless it is wished to prove a boiler to a bursting pressure, the superior strength of iron is not of any direct practical value, in existing practice, as a stay-bolt. The question is one, not of strength, but of durability; and the drift of evidence appears generally in favour of copper bolts—iron bolts proving, in general, more susceptible of corrosion, and more liable to snap. Individual makers place iron stay-bolts in the uppermost two or three rows; and the remainder of copper, as lying more within the latitude of corrosive influences. Too great stress has been laid on the superiority of the strength of iron over copper, as a material for stay-bolts; and where cheapness tells in favour of a substitution, as of iron for copper, the mechanical inducements to make the change should be decided. They are not so in the present condition of the question, and therefore, in our judgment, copper should be preferred for the material of stay-bolts. Another question supervenes, of much greater import, as to the quality of the water used in locomotive-boilers, for that is, no doubt, one cause of corrosion; to this question we shall return at another time.

It is obvious that, in the way boilers are constructed, the entire pressure on the roof of the firebox, or, strictly, upon the horizontal area of the base of the firebox, must be resisted by the stay-bolts and the mediums of junction at the base; and it is not impossible that the downward pressure considerably strains these lateral overhung supports; besides, the rates of expansion of iron and copper under varieties of temperature are different. A locomotive-boiler is observed to expand $\frac{3}{16}$th inch in a length of 15 feet, or, say, 1 in 1000, in rising from an ordinary temperature of 62° to 365°—the temperature of steam of 150 lbs. pressure per inch. Again, according to ordinary unauthenticated tables, copper expands by heat half as much again as iron, and, taking the mean temperature of the copper of the firebox at twice as much as that of the shell,—an assumption which, we suppose, is something much below the fact,—the vertical expansion of the firebox would be, upon the whole, three times as much as that of the shell, and the difference of expansion would be twice that of the iron, or at the rate of 1 in 500. On a firebox 5 feet 3 inches high, the difference of expansion would, at this rate, amount to $\frac{1}{8}$ inch. That is to say, the upper stay-bolts would be deflected $\frac{1}{8}$ inch from their normal position, when under the power of high-pressed steam. On a length of 3 inches, a deflection of $\frac{1}{8}$ inch is immoderate; and, considering the alternate expansion and contraction, bending and relaxing, attendant upon getting up steam and letting it down, it is reasonable to conclude that the same cause of degradation is at work with the stay-bolts as that already suggested for boiler-plate at the rivet-joints,—the alternation of strain, tension, and relaxation, which loosens the texture, and ultimately overpowers the cohesion of the material so treated,—incurring partial fracture and accelerated corrosion. On this argument, the failure of stay-bolts should, as in fact it is,

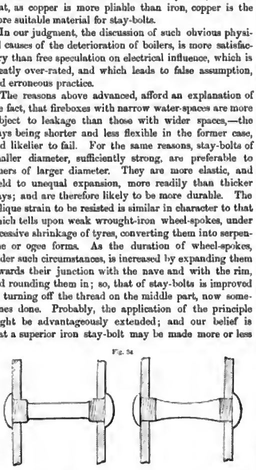
be localized at or near their junctions with the plates, which are the points of maximum strain, similarly to the localization of furrows near rivet-joints. Occasionally, entire rows of rivets are found to have snapped across, close to the plate, independently of corrosive action; suggesting a cause of failure precisely the same as that which breaks axles,—an alternating lateral strain and relaxation, beyond the limits of enduring elasticity.

If this be the cause of the failure of stay-bolts, it follows that, as copper is more pliable than iron, copper is the more suitable material for stay-bolts.

In our judgment, the discussion of such obvious physical causes of the deterioration of boilers, is more satisfactory than free speculation on electrical influence, which is greatly over-rated, and which leads to false assumption, and erroneous practice.

The reasons above advanced, afford an explanation of the fact, that fireboxes with narrow water-spaces are more subject to leakage than those with wider spaces,—the stays being shorter and less flexible in the former case, and likelier to fail. For the same reasons, stay-bolts of smaller diameter, sufficiently strong, are preferable to others of larger diameter. They are more elastic, and yield to unequal expansion, more readily than thicker stays; and are therefore likely to be more durable. The oblique strain to be resisted is similar in character to that which tells upon weak wrought-iron wheel-spokes, under excessive shrinkage of tyres, converting them into serpentine or ogee forms. As the duration of wheel-spokes, under such circumstances, is increased by expanding them towards their junction with the nave and with the rim, and rounding them in; so, that of stay-bolts is improved by turning off the thread on the middle part, now sometimes done. Probably, the application of the principle might be advantageously extended; and our belief is that a superior iron stay-bolt may be made more or less

Fig. 34



of the forms, Fig. 34, in which a $\frac{7}{8}$-inch screw is turned down to $\frac{1}{2}$ inch or $\frac{5}{8}$ inch diameter at the middle.

It has been remarked that when the brackets by which the firebox-shell is supported upon the frame are small, the adjoining stay-bolts are liable to be overstrained, and leakage is incurred. To avoid this, and to distribute the strain, the brackets should be co-extensive with the firebox-shell.

Material of Boilers.—As there is a limit to the strength of boilers, in the imperfection of the rivet-joint ordinarily made, it is probable that increased strength will be sought in the double-welt, or in the welded joint, with thicker iron plate, or in steel plate. Welded steel plates are likely to be adopted ultimately for locomotive-boilers; first, because they are strong; second, because they are sound. A total absence of flaw is the chief desideratum in boiler-plate, especially such as is subjected to fire on one side and steam-pressure on the other; and tough, homogeneous steel is the thing wanted. It would answer well for fire-boxes,—thin, tough, and strong, with a superior power of resisting corrosion; in expansibility by heat, it is nearly equal to iron, and could be used in conjunction with it.

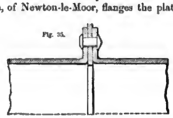
Steel tubes are now successfully manufactured; they are cheaper than iron or brass tubes, are harder than either, and wear well.

In fine, locomotive-boilers may be advantageously made of steel throughout,—shell, firebox, and tubes; at least, the firebox may be of steel, and the shell of Yorkshire iron plate, with tubes of brass. Large boilers, of the Cornish type, have been made entirely of steel, and they work very well.

Binding Hoops.—The use of steel plate in the construction of boilers would probably introduce other modifications in detail. There is one which might be employed beneficially in iron boilers,—fortifying the boiler by the application of hoops shrunk at intervals upon the barrel of the boiler, as wrought-iron hoops are shrunk on the cylinders of water-presses. An important accession of strength would be thus likely to be acquired, by a proportionally small addition of metal. The proposed hoops would act as a series of abutments for the intermediate sections of the boiler: just as the ends of the boiler bind and strengthen the terminal portions of the barrel. In proving the ultimate strength of a boiler of great length in proportion to its diameter, the central portion is the first to fail. What we suggest is, to apply intermediate abutments.

Resistance to Collapse.—Mr. Fairbairn, dealing experimentally with the converse problem,—the influence of length on the resistance of tubes to collapse by external pressure,—found that the resistance of tubes, fixed at the ends, varied inversely as the length; and Mr. Harvey, of Hayle, finds that long flue-tubes are materially strengthened against collapse by the insertion of angle-iron hoops at intervals within them; so much so as to enable him to construct the flues of thinner plates than otherwise. Mr. Adamson, of Newton-le-Moor, flanges the plates of flues,

Fig. 35.



and rivets them together, with a ring between them, as in Fig. 35; this plan is used in the construction of the large-flue engines of the Stockton and Darlington Railway, working at moderate pressure, and gives satisfaction. At the high-pressures now generally used, we do not consider this arrangement sufficient for large flues, particularly when they are flat-topped, as in combustion chambers; these are not to be trusted without stay-bolts in the circular parts, as well as girder-stays on the flat tops, pitching the bolts at, say, twice the interval adopted in staying the firebox. The small flue-tubes are practically beyond the danger of collapse.

PHYSIOLOGY OF THE BOILER:—OF FUEL AND COMBUSTION.

CHAPTER I.

THE COMBUSTION OF COKE.

IT has already been shown by the author, by a process of mechanical analysis, that the combustion of coke in the firebox of the ordinary locomotive is practically complete.* The whole heat of combustion of 1 lb. of good sound coke was found ordinarily to be disposed of as follows, when the temperature in the smokebox did not exceed 600° Fahrenheit:—

78 per cent. in the formation of steam.
16½ per cent. loss by the heat of the gases in the smokebox.
5½ per cent. drawback by ashes and waste.

100 parts.

This appropriation of the performance of 1 lb. of coke, is based on the chemical fact, that the maximum evaporative power of pure coke, entirely carbon, is expressed by a trifle more than 12 lbs. of cold water at 60° evaporated into high pressure steam, by 1 lb. of coke. Of this ultimate performance, 78 per cent. represents the evaporation of 9½ lbs. of water, and 16½ per cent. represents the heat carried off by the products of combustion, which, if economized, would evaporate extra 2 lbs. of water.

These conclusions, based on a mechanical analysis, and published in 1852, were, it is satisfactory to add, subsequently corroborated by the results of a chemical analysis, in 1853, of the products of the combustion of coke in the engines of the Paris and Lyons Railway, by MM. Ebelmen and Sauvage. They experimented with passenger and goods engines; and they found that the proportion of carbonic acid contained in the gases collected from the tubes at the smokebox end, was greater than is found in the gases from ordinary boiler-furnaces; whilst the proportion of free oxygen due to the excess of air in the draught was *less* in the locomotive.

In the passenger engines, and mixed-traffic engines, it was found that the proportion of carbonic acid varied from 12 to 18½ per cent. of the total volume of gases without any trace of carbonic oxide:—showing the entire conversion of the carbon into carbonic acid, and also, in the latter case, of all the oxygen admitted to the furnace. With the aid of good stoking, the proportion of carbonic oxide, or imperfectly burnt carbon, rarely exceeded 2 per cent. of the whole mixture. In the goods-engines, with deep charges of coke, a greater proportion of carbonic oxide was produced. When the fire was 40 inches deep, there was 7½ per cent. of oxide; in this country, that would be reckoned an extraordinary depth, much beyond ordinary practice. When the steam was shut off, the production of carbonic oxide rose as high as 12 per cent. of the entire volume.

CHAPTER II.

OF COAL, AND ITS COMBUSTION.

The complete, smokeless combustion of coal, as fuel in locomotives, is the chief question of the day in railway economics; and engineers are busy with the practical solution of the problem. The chemical history of the combustion of coal, in its practical relations, has been repeatedly and thoroughly explored by competent men. Of these, the earliest and most conspicuous is Mr. Charles Wye Williams, of Liverpool, to whom the world is much indebted for the thoroughness, impartiality, and lucidity with which he has treated the subject, and the unwearied pertinacity with which he has sought to impress his views on the public mind. Much ridiculed he has been, no doubt; that is because, feeling strongly, he has, with emphatic iteration, dwelt upon elementary truths which nobody was supposed to question. Scandalized he has been, too; that is because, regardless of the feelings and interests of others, he has denounced as empiricism and quackery, that which violated his sense of "chemical propriety." Nevertheless, Mr. Williams has laboured well and efficiently in the cause of coal-combustion and smoke-prevention.†

The question of the prevention of smoke has been intimately associated with that of the combustion of coal; and it is expedient now to treat them conjointly. They are, indeed, essentially one question, for, if coal be completely burnt, there cannot be any smoke; and, otherwise, if there be smoke, the coal is certainly not completely burnt. Before proceeding further, it may be well to interpose a definition.

Definition.—*Smoke* is the visible cloud that emerges from the chimney of a furnace, consisting of the volatile products of combustion, made visible. Most of the products, individually, are not visible; but, when collectively they are visible, they are called smoke. Smoke is of various colours, of various hues,—yellow, brown, black.

The obnoxious ingredient, or colouring matter, of smoke, consists either of unburnt gas, or of the matter of coal in a highly comminuted state, escaped unburnt from the furnace. But ordinary coal is not a homogeneous substance: the combustible matter of it is found, by analysis, to consist mainly of carbon and hydrogen:—carbon, dull and unevaporable,—hydrogen, the most elastic gas known,—at the extremes of the scale. As coke and anthracite coal give no smoke during combustion, although composed of the very matter of smoke,—of almost pure carbon,—it follows that the property of smoke-making is in some way connected with the hydrogen of coal; and that this gas, the most perfect type of gaseity known in chemistry, is really the cause of those difficulties which stand between us and the coveted desideratum of a smokeless coal-burning locomotive-engine. The constituent hydrogen is associated in chemical union with a portion of the carbon, forming with it a complex group of compounds, known collectively as hydro-carbons, which present themselves in various forms, when separated or distilled, by the application of heat. At the lowest temperature, the

* *Railway Machinery*, page 122. *Railway Locomotives*, page 122.

† See *The Combustion of Coal and the Prevention of Smoke Chemically and Practically Considered*, by Mr. Williams. London, 1854. Also, by the same author, *Prize Essay on the Prevention of the Smoke Nuisance*, Second Edition, 1857.

products obtained are chiefly oils, resins, and like distinctive compounds, vaporizable at temperatures under red heat. A somewhat higher temperature brings off fluids of volatile character, as naphtha. A higher still, the third stage of temperature, produces the rich illuminating gas, olefiant gas or bi-carburetted hydrogen. The fourth stage discharges the common gas, carburetted-hydrogen, which continues to be given off after the coal has reached low red heat. But, as the temperature rises, pure hydrogen also is given off; until, finally, in the fifth and last stage, hydrogen gas alone is discharged. What remains is the fixed or solid carbon of coal,—the coke; with earthy matter,—the ash of the coal.

These hydro-carbons,—especially those which are given off at the lowest temperatures, which are richest in carbon,—constitute the flame-and-smoke making part of the coal; and the greater their entire weight as compared with that of the fixed carbon, the more highly is this character developed. When subjected to degrees of heat much above the temperatures required to vaporize them, they become decomposed, and pass successively into more and more permanent forms, by precipitating portions of their carbon. At the temperature of low redness, none of them are to be found, and the olefiant gas is the densest type that remains, mixed largely with carburetted hydrogen, and free hydrogen. It is in these transformations that the great body of smoke is produced, when the precipitated carbon passes off uncombined; even olefiant gas, at a bright red heat, deposits half its carbon, changing to carburetted hydrogen; and this gas may deposit the last remaining equivalent of carbon, at the highest furnace-heats, becoming pure hydrogen.

Throughout all the primary and secondary conditions of the hydro-carbon compounds raised by distillation from coal, the hydrogen maintains the first claim to the oxygen present above the fuel; until it is satisfied, the precipitated carbon remains unburnt.

The following summary, Table No. V., presents the mean composition and characteristics of English, Welsh, and Scotch coals, derived from the *Report on Coals Suited to the Royal Navy*:—

TABLE No. V.—OF THE MEAN CHEMICAL COMPOSITION OF COALS.

Locality	Constituent Elements, by Weight.						Coke left by Distillation.	Water evaporated per pound of Coal.
	Carbon.	Hydrogen.	Oxygen.	Nitrogen.	Sulphur.	Ashes.		
	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Ct.	Per Cent.	Lbs.
Wales, 36 samples.	83·78	4·79	4·15	0·98	1·43	4·91	72·60	9·05
Newcastle District, 18 samples.	82·12	5·31	5·69	1·35	1·24	3·77	60·67	8·37
Lancashire, 28 samples.	77·0	5·32	9·53	1·33	1·44	4·88	60·22	7·94
Scotch, 8 samples.	78·53	5·61	9·69	1·0	1·11	4·03	54·22	7·70
Derbyshire, 7 samples.	79·68	4·94	10·28	1·41	1·01	2·65	59·22	7·58
Gross Means,	80·22	5·29	7·67	1·33	1·25	4·05	61·49	8·13

It appears from this summary that the composition of British coals averages, about 80 per cent. of carbon, 5 per cent. of hydrogen, 8 per cent. of oxygen, 1¼ per cent. of nitrogen, 1¼ per cent. of sulphur, and 4 per cent. of ashes; also, that the coke or fixed carbon, as distinguished from the volatilized carbon, averages a little over 60 per cent. of the weight of the raw material; leaving the difference of 80 and 60, or 20 per cent., of carbon, to pass off with the hydrogen, forming hydro-carbon compounds. The disposition of the elements in combustion would, then, be as follows:—

Volatilized hydro-carbons,....	Hydrogen,	5 per cent.
	Carbon,	20 per cent.
Fixed carbon, or coke,............................		60 per cent.
Oxygen, nitrogen, sulphur, ash,................		15 per cent.
		100 parts, by weight.

The consideration of the conditions of the perfect combustion of coal, is reserved for the next chapter.

CHAPTER III.

The Chemistry of the Combustion of Coal.

One pound of hydrogen unites with, and requires, 8 lbs. of oxygen for its combustion; measuring by volume, one cubic foot of hydrogen requires just half a cubic foot of oxygen for combustion; the product being steam, aqueous vapour, or water. Oxygen is sixteen times as weighty as hydrogen, and so hydrogen combines with eight times its weight, and but half its volume, of oxygen. In round numbers, 1 lb. of hydrogen is 200 cubic feet in bulk, at 62° Fah., and the combining volume of oxygen is 100 cubic feet.

One pound of carbon unites with 2⅔ lbs. or 32 cubic feet of oxygen for its complete combustion, forming carbonic acid. One pound of carbon may also unite with but half this quantity of oxygen, 1⅓ lb., or 16 cubic feet; being a case of incomplete combustion, and forming carbonic oxide.

Atmospheric air is composed of oxygen and nitrogen in the proportion of 1 lb. of the former to 3⅓ lbs. of the latter; or, by volume, 1 cubic foot of oxygen to 4 cubic feet of nitrogen. Nitrogen is a neutral gas, in combustion, and is present as a diluent simply; and for every cubic foot of oxygen required in combustion, 5 cubic feet of air must be supplied.

It follows that, for the combustion of 1 lb. of hydrogen, 500 cubic feet of air are required; and for the complete combustion of 1 lb. of carbon, 160 cubic feet of air are required.

These are the combining proportions of hydrogen and carbon with oxygen, and air, in combustion. In practice, the presence of an excess of oxygen above that which is chemically appropriated, is essential to the completeness of the combustion of the volatilized portions; but the amount of excess necessary becomes less as the general temperature in the furnace becomes greater. It is not needful, for present objects, to entertain the question of excess of air specifically, nor the relative demands of the varieties of hydro-carbons generated from coal. It suffices to show, generally, the proportions of air required for full chemical union with the volatile and the solid portions of the fuel; and thus to illustrate the relative importance of the claims of the gases upon the general oxygen-fund. It was shown that the average proportion of volatilized hydro-carbons was 25 per cent., by weight, of the whole body of coal, of which the hydrogen constituted 5 per cent., and the carbon 20 per cent.; and that there remained 60 per cent. as solid carbon. For illustration, take 100 lbs. of coal; then

the relative quantities of air chemically consumed in completely burning the combustible elements, are as follows:—

Volatile,	Hydrogen,	5 lbs.	consumes	2500	cubic feet	of air.
	Carbon,	20 lbs.	do.	3200	do.	do.
				5700		
Fixed,	Carbon,	60 lbs.	do.	9600	do.	do.
		85 lbs.	do.	15,300	do.	do.

In round numbers, for the complete combustion of 100 lbs. of coal, that is, of its combustible elements, 15,000 cubic feet of air is chemically consumed; or 150 cubic feet for 1 lb. of coal. And, of this supply of air, the volatile and fixed elements consume respectively, for the volatile, about 40 per cent., and, for the fixed, 60 per cent.; showing that, of the whole quantity of air required for chemical consumption, two-fifths, or nearly one-half, is demanded by the combustible gases.

If allowance be made for the excess of air practically required for the complete combustion of the gases,—say, three-fourths more than the chemical equivalent,—the total supply of air required for the combustion of 100 lbs. of coal, would be as follows:—

Volatile elements,	9975, or, say, 10,000	cubic feet	of air.
Fixed element,	9600, or, say, 10,000	do.	do.
Total for 100 lbs. of coal,	20,000	cubic feet	of air.

Thus, finally, it is estimated, that for the complete combustion of 100 lbs. of coal of average composition, 15,000 cubic feet of air are chemically consumed; and that 20,000 cubic feet of air are required in practice, or, 200 cubic feet of air for 1 lb. of coal, of which one-half is devoted to the fixed portion of the fuel, and one-half to the volatile portion.

The importance of the share in the business of the furnace, taken by the volatilized parts of the fuel, evidenced by the large proportion of air allotted to it, is enhanced by the reflection that the development of heat by combustion is generally in the ratio of the quantity of oxygen chemically combined in the process; and that, thus, the heat developed by the complete combustion of the volatile elements, is 40 per cent. of the entire quantity of heat generated. There is, then, scope for the economization of fuel, as well as for the prevention of smoke; but, as there is no doubt that much of the air consumed in burning the volatile elements is drawn through the grate, in company with that which is devoted to the solid portion, there remains so much the less fresh air to be thrown in above or beyond the fuel. There are, doubtless, empiricists who do not believe in the increase of economy by smoke-prevention. Unquestionably, however, when the prevention of dense smoke is not accompanied by a material saving of fuel, there must be a want of adjustment of the appliances, and necessarily imperfect combustion. Carbon, as already stated, may combine with oxygen in one of two proportions, forming carbonic oxide and carbonic acid, of which both are colourless, but in the production of the former of which, much less heat is developed than in that of the latter.

Besides the combustibles, hydrogen and carbon, the other elements of coal,—oxygen, nitrogen, and sulphur,—are driven off by volatilization. The oxygen, constituting 8 per cent. of the entire mass, may possibly take up its equivalent of hydrogen in the process of separation; but it cannot do much in this way, as the entire 8 per cent. of oxygen could, on that supposition, take up but 1 per cent. of hydrogen, as its chemical equivalent. Ammonia is the product of the union of hydrogen and nitrogen, and may possibly, in like manner, be driven off direct from the coal. However the chemical details of combustion may be developed, it is certain, as a fact, that hydrogen from coal, practically monopolizes a considerable portion of atmospheric oxygen, for the supply of which, therefore, to the hydrogen, provision must be made, without prejudice to the requirements of the fixed carbon, in order to effect complete combustion.

Much discussion has arisen on the question of the effective heating power of hydrogen raised from coal, and its value in that respect compared with carbon. Discussion of this kind is not likely to prove of much utility, so long as one essential element in the question, the amount of heat absorbed from the general stock, or rendered latent, in gasifying the hydro-carbons, with which the hydrogen is chargeable, continues to be an unknown quantity; as the evaporative efficiency of hydrogen is measured by the quantity of heat developed in its union with oxygen, minus the heat absorbed in the preliminary gasification. One thing is clear, that, in order to make the best of it, the hydrogen, once volatilized, should be oxidized, as well as the carbon associated with it, in order to realize the large measure of heat generated by their combustion. There is a favourite theory, having at least the merit of simplicity, that the heating power of coal is just equal to that of the coke derived from it, which is manifestly absurd. It would be nearer the truth to say, that the heating power of coal is measured by that of its constituent carbon. The evidence of the evaporative powers of coals abstracted in Table No. V., page 19, appears to support this mode of estimation, in so far as the evaporative efficiency varies generally with the percentage of constituent carbon. The percentages of constituent hydrogen vary within narrow limits, and do not afford data for any marked comparison; but it may be suggested that, generally, the evaporative efficiency is less as the constituent hydrogen is greater in quantity. Neither the variations of the hydrogen nor those of the carbon, however, suffice to account for the comparatively wide differences of efficiency; but, on referring to the next column,—of the constituent oxygen,—it is remarkable that the efficiency of the fuel decreases regularly as the percentage of oxygen in the fuel increases. Welsh coal, with about 84 per cent. of carbon, and 4 per cent. of oxygen, evaporates 9·05 lbs. of water per lb. of fuel; whilst Derbyshire coal, with about 80 per cent. of carbon, and 10 per cent. of oxygen, evaporates only 7·58 lbs. of water per lb. of fuel. The difference of carbon does not sufficiently account for the difference of evaporative efficiency; nor does the difference of hydrogen, which is practically the same in both cases. The prime cause, apparently, is the oxygen, which is in great excess in the inferior coal; and an explanation readily occurs. All this oxygen must, in the first place, be volatilized, and it must absorb a portion of heat, which is thus diverted from the business of evaporation; and though, no doubt, it may subsequently restore the heat thus temporarily abstracted, in combining with the hydrogen as a gas, yet, as compared with atmospheric oxygen, which, in the absence of solid oxygen, supplies its place, the solid oxygen is at a

disadvantage, in so far as atmospheric oxygen is yielded at once in the half-converted, desirable condition of a gas.

It appears, then, that the evaporative efficiency of coal varies directly with the quantity of constituent carbon, and inversely with the quantity of constituent oxygen; but that it varies, not so much because there is more or less carbon, as, chiefly, because there is less or more oxygen. The percentages of constituent hydrogen, nitrogen, sulphur, and ash, are practically constant:—with individual exceptions, of course; and their united influence should be so also. Practically, then, treating the question as one of evaporative efficiency, the solution of it lies between the carbon and the oxygen. The author, so far as he is aware, is singular in the suggestion of this solution of the question; he announces it now, in the expectation that it may be tested by more minute investigation. Found correct, it may serve to explain much that now seems anomalous in the heat-giving properties of coal.

CHAPTER IV.

Physical Conditions of the Complete Combustion of Coal.

It has been seen that coal, undergoing combustion, is exhibited in two forms,—solid and gaseous; of which the solid,—coke,—rests on the grate; and the gaseous, hydro-carbons and hydrogen,—rise from the solid portions. To get the air into immediate contact and mixture with these elements, so as completely to burn them, individually and in detail, is the important problem the solution of which has been the study of engineers. The mode of so introducing and mixing the air, depends on the circumstances of the furnace. If the draft be strong, or the depth of fuel upon the bars be small, all the air necessary for effecting the complete combustion of the fuel may be passed through the grate. If the draft be mild, or the depth of fuel considerable, or if by the nature of the fuel the quantity of air that can be passed through the grate is limited, then a large proportion of the air must be introduced otherwise, above the fuel, there to mix with and consume the gases. There are cases embracing both extremes in practice, as well as every variety of intermediate condition, and it is clear that every case must be prescribed for individually, in which the proportions of air introduced below and above the fuel are adjusted to the exigencies of each case. The introduction of air through the grate is, in ordinary practice, the fundamental condition; the admission of air otherwise, above the fuel, is auxiliary or supplementary to it, supplying just the additional quantity of air requisite to complete the combustion. In the practice of stationary boilers, it is usually necessary to admit a considerable proportion of air above the fuel. But where, as in locomotive-practice, a very powerful draft is maintained, the supply of air drawn through the grate, whilst the draft is in action, may alone suffice for the complete combustion of the fuel.

Again, the temperature should be maintained at a sufficient elevation, or, more correctly, it should not be lowered by external causes, during the combustion of the hydro-carbon gases, in order to effect the union of the carbon element with its full proportion of oxygen. In chemical order, the hydrogen discharges the associated carbon, and unites with oxygen; by this union, intense heat is generated, which envelopes the separated carbon-particles, and raises them to a white heat. Becoming thus luminous, and being the matter of flame, the carbon, in its intensely heated state, is prepared to unite with its saturating proportion of oxygen; and the union is effected the instant they meet, should the carbon retain its temperature until it gets into contact with oxygen. Upon this contingency depends the final condition of the precipitated carbon, whether as unburnt, uncombined particles,—the colouring matter of smoke; or as the product of combustion, carbonic acid. Should the carbon-particles miss the opportunity of uniting with oxygen, whilst yet at the high temperature which qualifies them to unite, it becomes practically impossible to restore them to the combining condition, and they inevitably pass away as smoke.

It follows, in the fourth place, as a condition essential to the complete combustion of coal, that the combustible gases should be thoroughly mixed with their supply of air. When the streams or columns of hydro-carbon gases rise, undisturbed or unbroken, from the body of the fuel, they are decomposed in bands or films, at what may be conceived as their surfaces of contact, when the oxygen of the surrounding air unites, in the first place, with the hydrogen of the decomposed distillation, and, in the second place, with the carbon-particles. So far the combustion is complete:—watery vapour and carbonic acid are generated as the results of the union of the distilled gases and the oxygen. At this stage, however, a contingency arises, and a partial re-action may ensue; for, in the ordinary course of the circulation of the gases, the film or stratum of burnt gas mixes with, and loses itself amongst, the neighbouring hydro-carbon gases, and should there not be present a sufficiency of fresh atmospheric oxygen to continue the combustion in that quarter, the newly formed carbonic acid would be attacked by the hydrogen of the hydro-carbon, and resolved into its elements, of which the oxygen would be appropriated by the hydrogen, and the carbon would be re-precipitated simultaneously with the carbon separated from the newly formed hydrogen. It may be observed, however, that notwithstanding such occasional action and re-action, to which the carbon is subjected, and chargeable to the superior affinities of the associated hydrogen, the carbon may be in condition, as at first, to again unite with oxygen, and to be ultimately and completely burnt, —in the condition, namely, of a sufficiently elevated temperature. It is clear that a continuous process of intermixture is necessary to the completion of the combustion of coal:—bringing together successively fresh portions of the combining elements, and throwing the separated carbon in the way of fresh oxygen for its own proper combustion.*

The complication that usually characterizes the burning

* For a full, detailed account of the phenomena of the combustion of coal, the author begs to refer to the works of Mr. C. W. Williams, already referred to; in which the whole subject is treated lucidly and ably, scientifically and practically. See also *Three Reports on the use of the Steam Coals of the Hartley District of Northumberland, in Marine Boilers*, by Messrs. Armstrong, Longridge, and Richardson, recently published, containing valuable and original matter on the combustion of coal.

of coal is, then, both physical and chemical:—physical, because an intimate mixture, and a suitable proportion, of the elements concerned, is essential to the completeness of their conversion; chemical, because, — unfortunately for the special object of the furnace, which is, to generate heat,—the least important element, hydrogen, is precisely that which demands the preference, and must have its share of oxygen, before the claims of the staple element, carbon, can be really entertained and satisfied. The hydrogen must be driven off before the main business of the furnace commences. The occasional presence of oxygen and nitrogen, in considerable quantity, further complicates the process, as they must be volatilized and driven off, in the due course of distillation.

The act of combustion is the business of an instant, with respect to each particle consumed; and if the gas and air were supposed to be brought together, mixed in suitable proportions, and fired, the result would be an explosion,—instantaneous combustion. In practice, combustion proceeds not thus, by explosions at marked intervals; but continuously, in exact sequence with the progressive intermixture of the elements: new particles, coming together in successive instants, unite in successive instants,—each union an insensible detonation, and all, in consecutive order, merging, fluxionally, in a continuous process of conversion. It is demonstrable, then, that the mixing of the gases, with which combustion keeps pace, and measurable, in fact, by combustion, is a progressive operation, which requires space and time for its completion; and that the thorough and complete intermixture of the gases is the real practical desideratum in view of the completeness of the combustion.

That this is the desideratum in the practice of coal-burning, is suggested by a variety of indirect evidence. The fire-damp of coal-mines, which is a discharge of carburetted-hydrogen from coal, when mixed with air in sufficient quantity, instantly explodes on the approach of a naked light. Pure hydrogen alone mixed with oxygen, explodes on the application of a light:—that is a common chemical experiment. And with respect to the other element, carbon, in the likeness of coke, it is instantly and thoroughly burnt when oxygen gets into contact with it; of this there is abundant chemical evidence, and, within the firebox of the locomotive, it has also been shown, in a preceding chapter, to be immediate. Experience and practice, then, enforce the practical conclusions that the combustible constituents of coal, whether combined as hydro-carbons, or single, as hydrogen or as carbon, are instantly,—without any appreciable lapse of time,—converted, burnt, or oxidized, when well intermixed with oxygen in due proportion; that, when they are not so intermixed, combustion is necessarily partial, but proceeds precisely in pace with the intermixture; so that the time expended in completing the intermixture, is, in fact, that which is spent in completing the combustion. In fine, immediate mixture insures immediate combustion.

In next chapter, the adaptation of the ordinary locomotive-boiler for the combustion of coal will be considered, when the unfavourable conditions of limited space, and limited time will be discussed. In following chapters, a chronological account of coal-burning contrivances will be given, and also results of practice in locomotive-engines.

CHAPTER V.

Qualifications of the Ordinary Locomotive-Boiler for the Combustion of Fuel.

In applying practically the principles on which the complete combustion of coal is effected, to the ordinary locomotive-boiler, the problem has been surrounded with difficulty; so unfavourable are the circumstances, that it has by many been given up as an insoluble problem. The thorough mixture of the gaseous elements with air, within the firebox, is just the condition the fulfilment of which has constituted the main difficulty in dealing with the locomotive-boiler. Space is limited by the necessity for compactness and portability; and time is limited by the necessity for a high rate of combustion, and a rapid draft, in order to develope the needful power within a small compass. But the difficulty is not thus fully represented; because, space or capacity that is good for anything in burning coal, must be open, in order that the gases in progress of combustion may freely intermingle; whereas, the necessary extension of surface for the absorption of heat, by means of the ordinary flue-tubes, cuts up a large portion of the flue-capacity of the boiler, divides the burning gases into isolated streamlets, and thus effectually suspends the continuous intermixture instrumental towards the completion of combustion. The gases in front of the tube-plate enter the tubes just as they are located:—where the mixture is rightly adjusted, combustion may proceed within the tubes, and be there completed; where there is too much air, or too little, it does not proceed. In practice, the latter is the usual condition of matters; and, accordingly, when the columns of gas and air, released from confinement within the tubes, pass into the smokebox, and again commingle, combustion is frequently resumed there, when it may continue till the gases are dispersed at the top of the chimney. This is the cause of the blistering of smokeboxes and chimneys of ordinary engines where coal exclusively is burnt; they are occasionally made red-hot. Such results are not now, however, so common as they have been; for whilst the earlier engines passed off the gases at a high spontaneously-igniting temperature through their short boilers, the more recently made engines abstract more of the heat from the gases on their passage through the boiler, when the gases are of course discharged at lower temperatures.

The unfavourable action of the flue-tubes in suspending combustion, is commonly ascribed to their cooling the gases below the minimum temperature requisite for the maintenance of combustion, and thereby cutting short the process altogether. It is not so; because either the rate of conduction of heat through the substance of the tube, or the rate of absorption of the heat by the water, would be totally insufficient to account for the presumed fall of temperature. Carburetted-hydrogen, the combustion of which is the desideratum, burns at 800° Fah.; and it is known that, in engines doing heavy duty, the temperature of the gases, after having traversed the entire length of the tubes, is frequently above 800° in the smokebox; in short, it is known as a fact, that the gases do spontaneously re-ignite in the smokebox, where they are free to continue mixing with air drawn with them

into that compartment, or with air drawn into the smokebox by leaking joints. The cooling within the tubes is far from being so rapid as has been assumed.

Whilst coal-gas may inflame at any temperature not less than 800°, in which the first stage is the combustion of the elementary hydrogen, initiated at that temperature, it is remarkable that the second stage, the combustion of the elementary carbon, precipitated into a diluting atmosphere of steam, carbonic acid, and nitrogen, can only be initiated at some temperature very much higher than in the first stage,—for which it must in fact depend upon the prior combustion of the hydrogen. It follows that, in a confined situation, inside a small flue-tube, with a limited body of gas, and an extended absorbing surface, the temperature excited by the combustion of the hydrogen may be so far reduced, that the suspended carbon may fall in temperature below the degree necessary for combustion, before it is reached for this purpose by free oxygen. It is, in due course, precipitated, in part, upon the surface of the tubes, as soot; and in part carried off as smoke.

The interruption of the process of combustion within the flue-tubes, then, arises primarily from the suspension of the intermixing process, which is essential to the progress of combustion, by the separation of the burning elements into isolated streamlets. The gases and air which happen to be duly mixed on entering the tubes, burn off to the extent at least of the hydrogen in combination; a portion of the separated carbon also is consumed, the remainder is precipitated, and there ends combustion within the tubes.

An analogous operation takes place in marine boilers: the smokebox, or uptake, is the common receptacle in which the products of several furnaces, combustible and non-combustible, meet. These products are in various stages towards maturity. Some have an excess of air, which is passed through the bars uncovered with fuel, or through the firedoor when opened, there being a deficiency of heat. The products from other furnaces have an excess of heat, and a want of air; or, from others, a large quantity of gas unconsumed for want of air. Again, when the grate is well charged, and the fire clear, a large quantity of carbonic oxide gas is generated, having a high temperature. The various products thus recapitulated, meet and mix in the smokebox, each supplying the wants of others: combustion is of course renewed, they burst into flame, and the uptake and chimney become overheated.

The extended length of flue, or "run," available for the mixing and combustion of gases, pertaining to ordinary stationary boilers, contrasts forcibly with the limited firebox of the ordinary locomotive-boiler, in which the run is measured by the mean distance from the grate to the tubes. For a stationary boiler, 30 feet long, the run may be three times this length, in fireplace and flue, in which the mixing and the combustion may proceed leisurely, and may be finally matured; whereas, the run of a locomotive-boiler is not above half as many inches, —between four and five feet; strictly speaking, there is no run at all. The utility of the long run in stationary boilers is clearly established by the observation of the lengthened flame, indicating lengthened or deferred combustion in the flues. Mr. Williams found, in one instance, that the flame extended to a length of nearly 30 feet in the flues, before complete combustion was effected. The locomotive-boiler, then, as it stands, though most excellently suited for the combustion of coke, is, according to ordinary practice, on the worst possible plan for effectually consuming coal:—having neither time, space, nor run, to facilitate the process. The defects of the multitubular-flue system, in this respect, has been experienced in the practice of marine boilers, in which the prevention of smoke appears to have been as nearly impracticable as in locomotives.

There is, however, one condition favourable for smoke-prevention in the locomotive,—the peculiar intenseness of the combustion. Cornish stationary boilers, with flues indefinitely drawn out, burn coal at the low rate of 4 lbs. per square foot of grate per hour; common stationary boilers burn off 12 lbs. to 20 lbs. per foot per hour; locomotive-boilers consume 50 lbs. to 100 lbs. per foot per hour. The more intense the combustion, the less is the required run, notwithstanding the increased speed of the draft, as the process of conversion is accelerated in a still greater ratio.

The comparatively superior strength of the draft in locomotive-boilers is directly beneficial, in its power of drawing more or less air through the grate, available for the combustion of the gases. A large quantity of free air is thus drawn in, mixed with the gases, and is quickly united with them; and there is no doubt that, in this way,—by the introduction of air entirely through the grate,—the combustion of coal is frequently effected in the locomotive-boiler with very little smoke. The result is, however, variable, because the means are variable; and though an engine, whilst working with full steam, and a powerful blast, may thus consummate the process of combustion, those conditions are wanting when the duty is light, as the blast is soft, and the draft is powerless to draw through the mass of the fuel a sufficiency of free air. Still less favourable are the conditions when the steam is shut off after heavy duty:—the natural draft of the boiler being totally insufficient for the purpose. Thus it is, that the discharge of smoke is greatest when the engine is doing the least duty, and when the blast is off; and that, whereas, in other classes of boilers, there may be a liberal run for the gases undergoing combustion, and, more than that, a comparatively uniform duty and a uniform draft; in the locomotive-boiler, the run is reduced to a minimum, and the duty and the draft are extremely variable, being both greater and less than those of any other class of boiler.

It has been found, accordingly, that an extension of the grate-surface is attended with a diminution of smoke in the combustion of coal, as the same mass of fuel, spread over a larger area, is less in depth, and a larger quantity of free air may be drawn through it. The most efficient coal-burning locomotives, under the same circumstances, are those which have the largest grates; and these are found practically to require a very small proportion of air introduced above the fuel, whilst under the blast:—much less than Mr. Williams adopts for stationary or marine boilers.

Still further to assist in the prevention of smoke, in common locomotive-boilers, an auxiliary jet of steam may be thrown into the chimney, in order to maintain the

draft through the fire, when the steam is shut off from the engine. The steam-jet is a very serviceable adjunct; and no doubt it materially aids in the prevention of smoke. It is, indeed, an indispensable element in all existing plans for effectually burning coal in locomotives; and much of their superiority of performance, though nominally ascribed to other and more apparent characteristics, is based upon the action of the auxiliary jet.

Ordinary Management of the Fire.—With the inconveniently small firebox of a common locomotive-boiler to deal with, enginemen, of course, have various ways of treating the fire, to diminish the nuisance of smoke. They have relied chiefly on the instrumentality of the ashpan, the dampers, and the firedoor, in working the fire on a system of careful firing. The prevention of smoke, by these means, has been most successfully effected by rigidly controlling the admission of air through the grate, and adjusting it precisely to the requirements of the fuel; by similarly manœuvring the firedoor for the admission of air above the fuel; by stoking with large pieces of coal and deep fires for heavy duty, and smaller coal with shallow fires for lighter duty; by firing more frequently, the lighter the duty, and at all times keeping the bars covered with fuel, to prevent excessive local drafts through the grate. That much may be done in this way, there is no doubt. It is well understood that the nuisance of smoke on entering or waiting at stations,—where extra precautions are necessary to avoid the infliction of legal penalties,—may be very much, or, in mild cases, altogether subdued by thoroughly closing the ashpan, and preventing totally the passage of air through the grate, and by opening wide the firedoor; because, then the discharge of carbonic gases from the lower strata of the fuel is prevented, and that source of dilution stopped; and, again, the combustible gases distilled spontaneously from the fuel are met and consumed by the fresh air through the doorway. It is further to be noted, that low pitched doorways, at the level of the fuel, introduce fresh air to greater advantage than those which are set high, nearer the roof of the firebox; for the reason that, through the low doors, the air mixes more quickly and more freely with the gases as they rise, and the effective run is consequently greater than otherwise.

It is found advantageous, accordingly, for the diminution of smoke, to administer the fresh coal chiefly under the firedoor, upon the hind part of the grate, there to distil its gaseous elements; and subsequently, when thus relieved, to push it forward towards the tubes, and make way for a succeeding charge behind. The gases arising at the back of the firebox mix with air as best they may, and at least get the chance of combustion on their way to the tubes, increased by every additional inch of run, the value of which is known to economizing enginemen, and acknowledged, notwithstanding the extra labour of stoking. The advantage arising from this arrangement of the fuel is popularly ascribed to the passage of the smoke over the incandescent fuel in advance. It is due simply to the opportunity afforded for intermixture and consequent combustion.

Coal is now very generally used in conjunction with coke, as fuel, in proportions varying according to circumstances, from one-third to two-thirds coal, to the remainder of coke; usually half and half of coal and coke. But it is a mistake to mix them, or to stoke them indiscriminately; they should be stoked separately, and, in general, the coke should be thrown towards the fore part of the grate, and the coal upon the hind part;—just as when, in using coal entirely, the incandescent or partially coked portions are moved forward, to make way for the green coal behind;—that the gases from the coal may have the run of the firebox. When coal and coke are fired indiscriminately, or in quick succession, coke over coal, which is done with a view to burn the smoke of the coal by the coke, the result is that, in the language of the stoker, "the coal burns the coke," or "eats it up;" which, being interpreted, signifies that the full value of the coke is not realized, because, probably, the coal monopolizes the greater part of the air from the grate, and the coke is for the most part only half-burnt, or converted into carbonic oxide, which developes little more than one-fourth of the heat generated in the formation of carbonic acid.

Small coal, and imperfectly converted coke, are occasionally watered with advantage, as a means of preventing smoke. The action of the water in the furnace may be partly mechanical, binding the loose particles; but it is chiefly chemical:—the elementary oxygen unites with a portion of the incandescent fixed carbon on the grate, forming carbonic acid, and the hydrogen goes towards reducing the heavier hydro-carbons into others lighter and better able to exist at high temperatures, holding their carbon in suspension. As an intermediate stage, this process equalizes the conversion of the gaseous element; and by such a play of affinities is it that the admixture of water is conducive to the prevention of smoke. A jet of steam thrown upon the fuel promotes the same object, partly in the same way; and, partly, by mixing the combustible elements.

Such, generally, are the usual modes of treating coal as fuel in locomotive-boilers of the normal type. The most is attempted to be made of the means, not precisely with a view to prevent smoke absolutely, but to restrain its production within parliamentary limits. The general result, though sensibly beneficial, is acknowledged to have been hitherto unsatisfactory; certainly it is not final, for the plans of working the fire are at best only compromises, involving the partial use of coke, and great attention in the management of the fire.

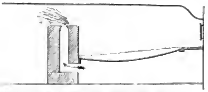
So much for the normal type of locomotive-boiler, exhibited in nearly all the engines of the present day. It is admirably fitted for burning coke, but it is not, as it now exists, fitted for burning coal; and the most important problem with which engineers have to deal, is, not the production of a new and distinct type of boiler for the perfect combustion of coal; but the production of a cheap, simple, effective method of insuring the complete, smokeless combustion of coal, conveniently and readily applicable to locomotive-boilers as they are. This is the desideratum of modern railway practice; it is an object the attainment of which is of urgent importance to railway engineers. Before discussing the probable direction in which a solution of the problem is to be sought, it is desirable to pass in review the various designs and expedients for the prevention of coal-smoke in locomotive-boilers, that have hitherto (1858) been tried or practised in England; referring the reader to the American division, for American experience.

CHAPTER VI.

Chronological Notice of Practised Inventions for the Combustion of Coal in Locomotives.

James Watt, in 1785, was the first on record who promulgated the idea of a separate supply of fresh air above the fuel, in coal fires, for the prevention of smoke. Josiah Parkes, in 1820, patented the split-bridge, Fig. 36, for

Fig. 36.

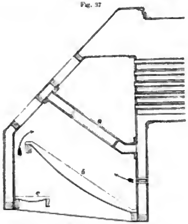


Smoke prevention by Split-bridge. Josiah Parkes, 1820.

the separate introduction of air beyond the fuel, to prevent the smoke of the furnaces of steam-boilers. A current of fresh air was introduced in a broad sheet, to meet with and consume the combustible gases from the fireplace. This plan gave good results under uniform conditions.

Gray and Chanter, Liverpool and Manchester Railway, 1837.*—One of the engines of the Liverpool and Manchester Railway, the "Liver," was fitted with a double firebox, Fig. 37, one chamber above the other.

Fig. 37



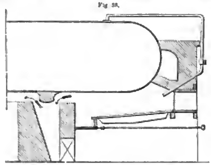
Coal-burning Boiler, by Gray and Chanter, 1837.

The chambers were separated by an inclined water-space partition, *a*, rivetted to the front and back of the firebox, but a little clear of the sides, and having the central portion formed into hollow bars. The lower grate *b*, of ordinary bars, was similarly inclined: it fitted closely to the front and sides, but was a little clear of the back. A short supplementary grate, *c*, was placed at the back of the firebox, below the others. Coke was burned on the upper grate, and coal on the lower, and the fuel that dropped from the latter was received by the supplementary grate. Each chamber had a hollow firedoor, through which air was admitted, and distributed through numerous perforations in the inner side of the door, to the fuels on the upper and lower grates respectively. Currents of air were also admitted through tubes in the lower part of the front of the firebox. Thus the air from below was heated in passing the supplemental grate; and the coal gases from the lower grate passed through the coke fire on the upper grate,—the object being to consume the smoke by passing it through incandescent fuel, and mixing it with fresh air from the doors. A steam-jet was applied in the chimney, to be turned on to maintain the draft, when the blast was off.

This plan comprised the first application of the auxiliary steam-jet in the chimney; and of divided currents of air above the fuel. The engine is said to have frequently run without smoke, when very carefully managed; but was not successful with ordinary management.†

M. W. Ivison, 1838.—A steampipe is led from the boiler, Fig. 38 (showing the application of the plan to a

Fig. 38.

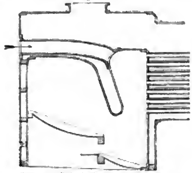


Smoke-burning Furnace, by M. W. Ivison, 1838.

stationary boiler), into the interior of the furnace, where it terminates above the grate; it delivers "streams of steam" amongst the gases rising from the fuel, in order, by mixing therewith, to consume the smoke, and perfect the combustion. The invention is said to have answered in stationary furnaces; it was tried on one of the locomotives of the Edinburgh and Glasgow Railway, but did not succeed.

Gray and Chanter, 1839.—In a second arrangement,

Fig. 39.



Coal-burning Boiler, by Gray and Chanter, 1839.

Fig. 39, the firebox was divided vertically into two chambers, not horizontally as before; so that the partition,

* In these notices, the dates are assigned as nearly as the author can determine, to the time when the inventions were first tried or practised.

† For the particulars of this engine, the author is indebted to *The Engineer*, 1857–58.

descending from the roof, was not covered by fuel, and an ordinary grate was added to the second chamber. The grates were inclined, and the forward grate smaller and lower than the other, step-fashion. Coal was charged on the hind grate, and coke on the fore, and it was designed that the gases distilled from the coal should be deflected by the diaphragm over the incandescent coke, and thus consumed. The coal gravitated, or was pushed forward, as it burned, upon the fore grate, to make room for fresh charges. This plan was tried on the Liverpool and Manchester Railway, burning one-third coke, and two-thirds coal; smoke was reported to have been abundant when standing; and when moving, much depended on the assiduity of the fireman.

C. W. Williams, 1839.—The system of Mr. Williams, Fig. 40, is that known as the Argand furnace, the prin-

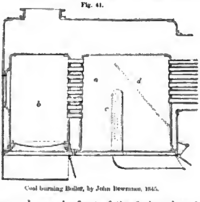
Fig. 40

Smoke-prevention Furnace, by C. W. Williams, 1839.

ciple of which is, that air is admitted above or beyond the fuel, in a divided state, in numerous small jets, to mix freely and thoroughly with the gases, in order to perfect the combustion. The system is applicable to boilers generally, and has been applied with success to stationary boilers, and, according to the reports of recent trials,* to multitubular marine boilers also.

John Dewrance, Liverpool and Manchester Railway, 1845.—This plan, Fig. 41, consisted in the addition of

Fig. 41.

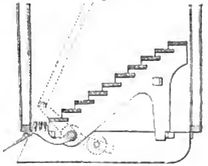


Coal-burning Boiler, by John Dewrance, 1845.

a chamber or box, *a*, in front of the firebox, *b*, and connected to it by short tubes; or, which amounts to the same thing, the firebox is divided into two parts by a vertical partition. The second compartment was reserved for the combustion of the gases from the first, being closed air-tight at the bottom, and air for combustion being introduced through perforated tubes, *c*, rising from the bottom, on Williams' system. This plan is said to have given favourable results; and the action was found to be improved by the addition of the deflector or baffle-plate, *d*, shown in dotting, in the combustion-chamber.

The Step-Grate, Great Northern Railway of France, 1851.—The design of this grate, Fig. 42, is to admit plenty of air through the bars, and to distil the gases from the coal, at or near the doorway, causing them to traverse the firebox, over the incandescent fuel in advance, and thus to facilitate their mixture with air. The bars are flat, arranged as steps, and lie across the firebox. The coal, when partially coked, is pushed forward to make

Fig. 42.



Coal-burning Boiler, with Step-grate, 1851.

way for a fresh charge, and as it advances it is gradually converted into smokeless coke. Thus, a body of incandescent fuel is accumulated and maintained near the tubes, and the fresh fuel is near the door. This grate has been extensively used in France; it works well with free, open coal; but with bituminous coal it fails,—burning the bars and stopping the air-passages.

In recent modifications, a small moveable horizontal grate is added at the fore end, as in the figure, to facilitate the removal of clinker and ashes.

The method of the step-grate, here exemplified, succeeds in virtue of the long run it affords, from the fresh coal to the tubes, which favours the completion of the combustion of the gases within the firebox. As, however, the addition of fresh coal is confined to the neighbourhood of the doorway, at the top of the grate, it demands uncommonly frequent stoking, with the occasional use of the poker.

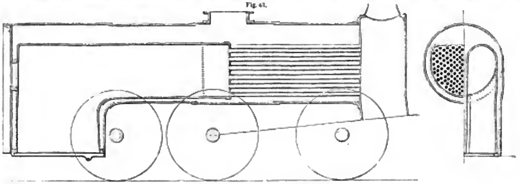
J. E. M'Connell, London and North-Western Railway, 1853.—In Mr. M'Connell's plan for prevention of smoke, Fig. 43, his principles appear to have been, first, to provide the greatest practicable area of fire-grate, in order that the coal might burn with moderate intensity, and free from clinker, and that plenty of air might pass into the firebox through the grate to consume the gases; secondly, to assist the combustion, by introducing air through the front and sides of the firebox; thirdly, to provide a large capacity and length of run by adding a combustion-chamber, which is simply an extension of the firebox into the barrel of the boiler; fourthly, to provide for alternate firing, by dividing the firebox longitudinally into two. This plan, with good management, is effectual in preventing smoke.

More recently, Mr. M'Connell has added a curtain-plate, which receives the entire charge of air through the

* *Reports on the Use of the Steam Coals of the Hartley District of Northumberland in Marine Boilers*, 1858.

doorway; the doorway is always open, and the air is distributed through numerous small holes in the fore part of the curtain. This distributive agency of the curtain-plate facilitates the completion of combustion.

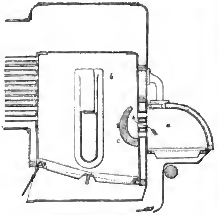
Fig. 43.



Coal-burning Boiler, by J. E. M'Connell, 1853.

Joseph Beattie, London and South-Western Railway, 1853.—An auxiliary and smaller firebox, *a*, was in this plan, Fig. 44, added behind the ordinary firebox, *b*, and joined to it by short tubes. In the main box coke was consumed as usual, and coal in the hind box, in the proportion of two-thirds coke and one-third coal. Thus, the gases from the coal, baffled by a fire-tile, *c*, passed through and had the run of the coke-firebox before they entered the tubes, and the combustion of the coal was quite complete.

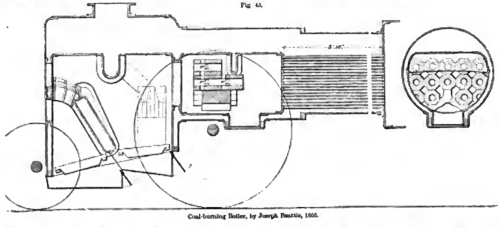
Fig. 44.



Coal-burning Boiler, by Joseph Beattie, 1853.

Joseph Beattie, 1855.—This boiler, Fig. 45, was designed to burn entirely coal without smoke. As in M'Connell's, the grate is large, and the run is extended by the addition of a combustion-chamber projected into the barrel. The firebox is divided transversely into two compartments, by an inclined water-space diaphragm. The back compartment is arched over with fire-tiles at narrow intervals apart; the combustion-chamber also is stocked with a faggot of perforated bricks placed at some distance clear of the tubes. The fire-tiles receive and retain a portion of the heat from the passing gases, when the fuel is incandescent and smokeless, and discharges it to the smoke passing from fresh coal: thus acting as equalizers of temperature. The tiles, also, break up and mix the gases and air; and, partly by mixing, and, it is supposed, partly by heating, they promote combustion. The first furnace is the most actively worked; the second is designed chiefly to carry incandescent fuel; and by means of independent ashpans and dampers, the admission of air through the grate may be adjusted for

Fig. 45.

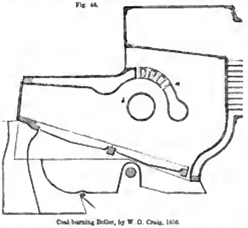


Coal-burning Boiler, by Joseph Beattie, 1855.

each furnace. Air is also admitted through the doors by small apertures, and, similarly, through the back of the firebox; adjustable by slides. The gases from the first and principal furnace pass through the tile-bridge, are deflected by the hanging transverse diaphragm towards the hot fire in the second furnace, are passed through the tiles in the combustion-chamber, and again deflected by a hanging diaphragm, before they enter the tubes. The scheme of this invention is, then, to equalize the temperature of the gases, to prepare the colder gases for ignition, under all fluctuations of temperature; and also to perfect the mixture of the gases and air, to effect their entire combustion. In recent designs, an additional brick arch is built against the entrance to the combustion-chamber, and a counter arch of flat tiles is carried from that to the hanging diaphragm in the firebox, shown in dotting in Fig. 45. An auxiliary steam-jet is opened into the chimney when the blast is off, to stimulate the draft, and prevent smoke. This plan works very well.

W. G. Craig, Manchester, Sheffield, and Lincolnshire Railway, 1856.—The characteristics of this design, Fig. 46, are, the long inclined grate, the curved descending diaphragm, *a*, and transverse water-tube, *b*, to deflect and mix the gases, and the mixing chamber above and in advance, into which the gases pass through the diaphragm and mix with fresh air there admitted. This

Fig. 46.

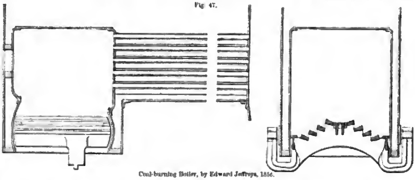


Coal-burning Boiler, by W. G. Craig, 1856.

plan has not been successful; probably, because the air-passages and mixing spaces are injuriously restricted, and aggravated by an excess of cooling surface.

E. Jeffreys, 1856.—The principle of this plan, Fig. 47, is that of a rocking grate, which is turned on a swivel, so as, by thus inclining forward, to slide the incandescent fuel towards the tubeplate, and make room at the back of the firebox for fresh coal. The bars are placed longitudinally, on their sides, and arranged to step down right and left, as in the step-grate, to admit abundance of air. This plan is said to work efficiently in preventing smoke, on the Shrewsbury Railway, with favourable kinds of coal.

Fig. 47.

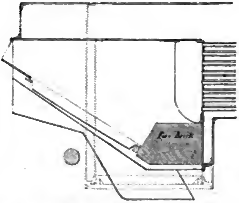


Coal-burning Boiler, by Edward Jeffreys, 1856.

Evans & Dubs, Chester and Birkenhead Railway, 1857.—A hanging mid-feather or diaphragm is inserted transversely, partially dividing the firebox into two compartments. The grate is inclined forward, and is moveable vertically. The fuel, as it is consumed, slides, or is pushed, forward towards the tubeplate. Before stoking, the grate is raised towards the diaphragm, and the fresh coal is thrown into the hind compartment, so that the gases from the fresh charge pass under, and through tubular openings, in the diaphragm, over and amongst incandescent fuel. As the fuel is consumed the grate is lowered. This plan failed at the outset, for want of draft in the hind compartment; which, indeed, is obvious enough, as the draft would not, unbiassed, both ascend and descend through the fuel.

J. J. Cudworth, South-Eastern Railway, 1857.—This plan, Fig. 48, combines the inclined grate, with a long

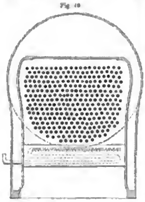
Fig. 48.



run:—the incandescent fuel sliding forward, the fresh coal is charged near the doorway. The firebox is divided by a longitudinal diaphragm into two compartments, making two furnaces, which unite in front of the tubeplate. The figure shows in dotting, the form of the original boiler, one of the "Folkestone" class, which was altered for burning coal. With the aid of an auxiliary steam-jet in the chimney, this plan is effectual in preventing smoke.

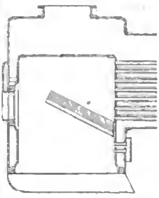
Besnier de la Pontonerie, Paris, 1857.—A small steampipe is laid from the boiler into the firebox in front, Fig. 49, which it traverses three times from side to side. The uppermost length of pipe is perforated with numerous small holes; so arranged, that the steam is discharged in a superheated state, just above the fuel, in an inclined direction upward, so as to meet and mix with the flame and destroy the smoke. This plan has been tried on the Eastern Counties and North London Railways, and was effectual in preventing smoke, with the aid of the blowpipe when the blast was off. But it tended to damp the fire, and caused a want of steam, with a heavy extra consumption of fuel. The steampipe failed by exposure to the fire, and in more recent instances it has been encased with firebrick, as shown in the figure.

Fig. 49.



Coal-burning Boiler, by Besnier de la Pontonerie, 1857.

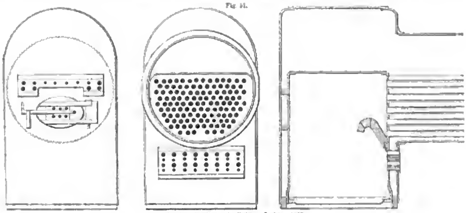
Fig. 50.



Coal-burning Boiler, by Thomas Yarrow, 1857.

Thomas Yarrow, Aberdeen Railway, 1857. — Mr. Yarrow divides the firebox by a transverse water partition, or a brick arch, or otherwise, based on the tubeplate, Fig 50, just below the tubes, and inclined upwards towards the firedoor. He also admits air through tubes in the walls of the firebox, and also through the door, to mix with the gases. By the interposition of the deflectors, Mr. Yarrow lengthens the run of his firebox, and promotes the combustion of the gases, with the assistance, when the steam is shut off, of a blow-pipe in the chimney.

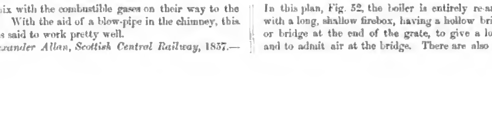
Fig. 51.



Coal-burning Boiler, by William Jenkins, 1857.

William Jenkins, Lancashire and Yorkshire Railway, 1857.—In this plan, Fig. 51, tubular stays are placed in the walls of the firebox, for the admission of air, regulated by slides; the air admitted through the front of the firebox is received by an inclined deflector, of iron or brick, erected against the tubeplate, within the firebox; and is distributed in streams, by a number of small passages, through the upper part of the deflector, to meet and mix with the combustible gases on their way to the tubes. With the aid of a blow-pipe in the chimney, this plan is said to work pretty well.

Fig. 52.



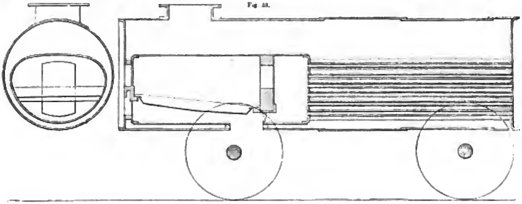
Coal-burning Boiler, by Alexander Allan, Perth, 1857.

Alexander Allan, Scottish Central Railway, 1857.—In this plan, Fig. 52, the boiler is entirely re-arranged, with a long, shallow firebox, having a hollow brick wall or bridge at the end of the grate, to give a long run, and to admit air at the bridge. There are also hanging

water-space bridges, to deflect and mingle the gases. With the aid of the blow-pipe, this plan seems likely to answer.

Mr. Allan has constructed another arrangement of boiler, Fig. 53, in which he uses a plain elongated firebox, and passes all the air and smoke through a moderated opening in a transverse firebrick diaphragm, so as to bring them together, and promote their mixture and combustion.

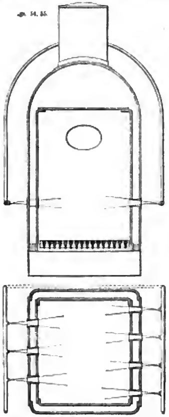
Fig. 53.



Coal-burning Boiler, No. 2, by Alexander Allan, Perth, 1857.

D. K. Clark, London, 1858.—This is the method of steam-inducted air-currents. A sufficient number of tubular or otherwise formed openings are made through the sides or other part of the firebox, Figs. 54 and 55, for the admission of air above the fuel; and jets of steam are projected through these openings, as indicated by the expanding outlines, to induct and forcibly distribute the air within the firebox, and enforce its immediate mixture and combustion with the gases:—the action of the jets of steam in creating powerful currents of air into the firebox, being similar to that of the blast-pipe in the chimney. This plan has been tried on the Eastern Counties Railway, and is quite successful in preventing smoke, making a bright fire, keeping up steam, and working economically. By inclining downwards the jets of steam, the air may be thrown at any desired inclination upon the fuel, and amongst the smoke.

Figs. 54, 55.



Coal-burning Boiler, by D. K. Clark, London, 1858.

George K. Douglas, Birkenhead and Cheshire Junction, 1858.—An iron hood or baffle plate is fixed inside the firebox, over the doorway, inclined downwards and towards the middle of the firebox, in order to deflect the air entering by the doorway downwards amongst the flame and smoke. This plan is reported to work well, with the aid of the blow-pipe when the blast is off.

Sylvester Lees, East Lancashire, 1858.—Mr. Lees builds a brick arch within the ordinary firebox, against the tube-plate, so as to intercept and direct towards the middle of the firebox, the flame and smoke rising at the fore part; and he fixes a plate-iron hood on the firedoor, inside, inclined downwards, so as to direct the air entering there also upon the fuel. This plan acts tolerably well, with the aid of the blow-pipe in the chimney, but the brick-work is troublesome to maintain.

Edward Wilson, Oxford and Wolverhampton, 1858.—A few of the tubes are extended through the smokebox, and bell-mouthed, to receive and carry air into the firebox.

On the London and North Western Railway, a firetile cylinder, 12 or 14 inches diameter, has been tried, resting on the grate, and rising through the body of the fuel, in the centre of the firebox; the upper end was furnished with a perforated crown, through which air from within passes into the firebox above the fuel, to mix with the smoke. Steam has been introduced in the same way, but it damped the fire.

CHAPTER VII.

Results of Practice in Coal-Burning.

In the years 1845–46, the "Condor" locomotive-engine, fitted with Mr. Dewrance's coal-burning apparatus, ran for some time on the London and North Western Railway, on regular duty, between Liverpool and Birmingham. It was treated like the other engines on the line; it was worked in various ways—with coke alone, with coke and coal mixed, and often with coal only, as fuel; and, it is said, no complaints were made against the engine, as to smoke-making. From the returns of the performance of that engine, it appears that she ran 1170 miles in six days, on regular duty, and consumed 211 cwts. of coke, besides 5½ cwts. of coal to get up steam; and that she ran the same distance in the six days immediately previous, on the same duty, consuming 149½ cwts. of coke, and 87½ cwts. of coal, besides 5½ cwts. of coal, as in the other case, to get up steam. Thus, 211 cwts. of coke did the same amount of duty as 149½ cwts. of coke, plus 87½ cwts. of coal; and, it may be inferred, the excess of 211 cwts. above 149½ cwts., or 61½ cwts., was equal in evaporative value to 87½ cwts. of coal. These quantities are in the ratio of 100 to 142, or as 2 to 2·8, and they show that nearly one-half more weight of coal was required to do the duty of coke, or, that their mechanical values in the "Condor" engine, were as 2 to 3 nearly.

In the years 1850–51, the Author made various comparative trials of the combustion of coke and coal, in the ordinary forms of locomotive-boilers, on some of the Scottish railways, already published; from which he concluded that, in the prevailing type of boilers, the evaporative powers of good coal and good coke, were as 2 to 3, coal doing, mechanically, just two-thirds of the duty of coke.* In all these instances, the combustion of the coal was obviously incomplete, as smoke, in considerable quantity, was discharged from the chimney.

M'Connell's Boiler.—Subsequently, in the year 1854, Messrs. E. Woods and W. P. Marshall tried the comparative mechanical values of coal and coke in the engines of the southern division of the London and North Western Railway. With one of the engines constructed on Mr. M'Connell's system, illustrated by Fig. 43, page *27, with a large firebox, a midfeather, and a combustion-chamber, comparative trials were made with Pease's West coke, and Hawkesbury Main coal, from Coventry, hard, clean, and free from clinker. This coal was found, according to Mr. Woods, to contain 67 per cent. of carbon, and 5 per cent. of hydrogen.† The ratio of the constituent oxygen is not mentioned, though it would appear, from the examination of the performances of various coals, in a previous chapter, page 19*, that that is an important element. The results of the trials are abstracted from the printed report, in Table No. VI. The steam was easily kept up, and smoke was prevented; though the latter depended very much on the skill and attention of the fireman. The engine was worked with a very thin fire, four to six inches thick, on a large area of grate, 22 square feet; the compartments being fired alternately, and very frequently,—say four or five times more so with coal than with coke, or once in every two or three miles.

TABLE No. VI.—OF THE PERFORMANCE OF M'CONNELL'S COAL-BURNING PASSENGER-LOCOMOTIVE, No. 300, ON THE LONDON AND NORTH WESTERN RAILWAY, BETWEEN RUGBY AND LONDON, WITH EXPRESS AND ORDINARY TRAINS, IN JUNE AND JULY, 1854.

Train.			Speed, &c.			Water.		Fuel.			Nett Consumption, excluding getting up Steam.							
Average Number of Carriages.	Weight of Train, Estimated.	Weight of Engine, Tender, and Train.	Average Length of Run between Stopping Stations.	Average Speed, including Stoppages.	Average Speed, excluding Stoppages.	Gross Consumption.	Per hour Blast on the Fire.	Description of Fuel.	Gross Consumption.	Gross, Per mile.	On Duty with Trains.	Per hour Steam on, or Blast on Fire.	Per hour per foot of Grate.	Per mile.	Per mile per ton gross.	Water consumed per lb. of Fuel, allowing 1 cwt. to get up Steam.	Weather.	Remarks.
Carriages.	tons.	tons.	miles.	miles per hour.	miles per hour.	cubic feet.	cubic feet.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lb.	lbs.		
16·6 up. 11·5 down.	72	120	16·3 3·0	35·0 24·3	38·0 28·3	573	159	Coke.	4163	25·3	4023	1111	51	24·5	·20	8·9	Calm, fair, showery.	Means of three double trips.
14·4 up. 12·0 down.	67	115	11·6 2·6	36·0 24·1	37·8 29·8	541	171	Coal.	5848	35·6	5708	1784	81	34·8	·30	5·9	Do., do.	Means of three double trips.
17·7 up. 27·6 down.	97	145	2·8 3·1	25·2 25·4	29·5 29·4	622	214	Coke.	4402	26·8	4262	1470	67	26·0	·18	9·1	Do., do.	One double trip.
16·4 up. 33·5 down.	127	175	2·3 3·2	24·0 24·3	28·8 28·0	725	258	Coal.	7650	46·6	7510	2682	122	45·8	·26	6·0	Do., do.	Means of two double trips.
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

Note.—1. The times of the blast on the fire, are estimated by deducting four minutes per stoppage from the whole time with the train.

2. The weight of the train is estimated at the rate of five tons per carriage, as adopted by Messrs. Woods and Marshall in former experiments; and one to two tons extra per brake-van.

3. The train mileage is 81½ miles up, and 82¾ miles down. Total per double trip, 164¼ miles.

4. The area of fire-grate is 22 square feet.

Averaging the Up and Down trains, there are the following results of the first performances with coal:—

Engine and tender,	48 tons weight.
Train, 13·2 carriages,	67 tons weight.
Engine, tender, and train,	115 tons gross weight.
Average speed, excluding stoppages,	33·8 miles per hour.
Gross consumption of coal,	35·6 lbs. per train-mile; or ·31 lb. per ton gross per mile.
Nett consumption of coal, on duty,	1784 lbs. per hour, steam on; 34·8 lbs. per train-mile; or ·30 lb. per ton gross per mile.
Consumption of water on duty,	171 cubic feet per hour, steam on; 3·29 „ „ per train-mile; 1·79 lb. per ton gross per mile; 5·9 lbs. per lb. of coal.

Doing the same duty with coke, the engine consumed

* *Railway Machinery*, and *Railway Locomotives*, pages 156 to 164.

† Discussion upon a paper by the Author, *On the Improvement of Railway Locomotive Stock, and the Reduction of the Working Expenses*, read at the Institution of Civil Engineers, November 11, 1856.

24·5 lbs. per train-mile, or ·20 lb. per ton gross per mile, and 8·9 lbs. water per lb. coke.

With heavy stopping trains, the engine consumed ·26 lb. coal per ton gross per mile, and 6 lbs. water per lb. coal; also, ·18 lb. coke per ton gross per mile, and 9·1 lbs. water per lb. coke. The results show, that the efficiency of the coal, in this engine, is just two-thirds of that of the coke, whether with regard to the gross weight of train, or the evaporative power. It does not appear from these results, that M'Connell's boiler realizes any higher duty from coal than ordinary boilers.

CHAPTER VIII.

Results of Practice in Coal-Burning—(*Continued*).

Beattie's Engine.—Early in 1856, the Author arranged and conducted several trials of one of the passenger-locomotives, the "Canute," on the London and South Western Railway, constructed on Mr. Beattie's system for burning coal. The boiler was fitted with two bodies of firetiles, one arching over the hind compartment of the firebox, the other piled into the combustion-chamber, as already exhibited in Fig. 44, page *27. The engine was fitted also with an apparatus for heating the feed-water, to deliver it at or near a boiling heat into the boiler. This apparatus was in two parts, placed within and above the smoke-box; when in operation, steam from the blast-pipe was exhausted into the condenser above, where it met the jet of cold water thrown in by one of the pumps, and was condensed by it; the feed-water, thus heated, flowed back into the tender, except what was intercepted by the other pump, with which a junction was made from the return flow-pipe, for supplying the boiler. The water sent into the boiler passed, on its way, through the surcharging-chamber in the smoke-box, where it acquired a further increase of temperature, previous to entering the boiler. The surcharging-chamber contained a number of tubes for heating surface; it was supplied with heat from the exhaust steam, which was thrown directly into it from the exhaust-pipes, on its way to the condenser. Thus, when the engine was at work, the feed-water was heated, by the first process, to or near the boiling point, and by the second process, presumably, to some point above that, having some relation to the initial temperature of the exhaust steam. The superfluous feed-water discharged from the condenser, returned to the tender, and raised the general temperature there.

The following are the particulars of the "Canute" passenger-engine:—

Cylinder, 15 inches diameter, 21 inches stroke.

Driving-wheel, 6 feet 6 inches diameter.

Firebox, inside dimensions—length, 4 feet 11 inches; breadth, 3 feet 6 inches; depth at back, 5 feet 1 inch; ditto at front, 4 feet 1 inch.

Combustion-chamber, 3 feet 6 inches diameter, flat-roofed, 4 feet 2 inches length.

Tubes, 373 in number—outside diameter, 1¾ inches; clearance between, $\frac{5}{16}$ inch; length between plates, 6 feet.

Ashpans, entrance, 3 feet 6½ inches long, 12 inches deep at the front, 9½ inches deep at the back.

Fire-grate, in two parts, 16 feet total area.

Heating surface, interior.—

Firebox,	107 square feet.
Combustion-chamber,	37 ditto.
Tubes,	625 ditto.
Total,	769 square feet.

Firebricks—

Gross weight, 5¾ cwts.

Heating surface of bricks, in contact with smoke, 80 square feet.

To find the ordinary quantity of heat contained in the firebricks, one of each form of brick was heated in an ordinary furnace, to the usual degree of redness when at work, and plunged into a large vessel of cold water The observed amount by which the temperature of the water was raised was multiplied into the quantity of water, and by the number of bricks of each form; and showed that the bricks contained upwards of 300,000 units of heat, equal to the heat derivable from 22 lbs. of carbon, which would evaporate 3 cubic feet of water.

The trials with the "Canute" were designed chiefly to test the performance of the engine, with the usual express trains; and to ascertain the economical advantages of the firebricks as smoke-preventers, and of the feed-water heating apparatus. The engine was therefore tried under various conditions:—with coal and with coke, with bricks or tiles, and without them, with hot and with cold feed-water.

The coal used was of three kinds, Llangnathog Merthyr (Welsh) coal, Griff coal (hard), and Stavely coal (soft). The coke was made from Ramsay's coking coal. The water supplied to the engine was hard; it was neutralized by an allowance of muriate of ammonia put into the tender.

The coals were delivered to the engine usually in equal quantities, of one-half of Welsh coal, and the remainder of Griff and Stavely coals.

The Table No. VII. contains an abstract of the results of the performance of the "Canute" engine, under varied conditions, described in the body of the table. The averaged performances of the engine show that, in regular order, with firetiles and feed-water heating apparatus, the "Canute" acquitted herself as follows:—

Engine and tender,	33 tons weight.
Train, 11 carriages,	69 tons weight.
Engine, tender, and train,	102 tons gross weight.
Average speed, excluding stoppages,	33 miles per hour.
Gross consumption of coal,	17·4 lbs. per train-mile; or
	·17 lb. per ton gross per train-mile.
Nett consumption of coal, on duty, exclusive of fuel for getting up steam, and running the engine empty,	554 lbs. per hour of steam on;
	15·3 lbs. per train-mile; or
	·15 lb. per ton gross per train-mile.
Nett consumption of water, on duty,	52 cubic feet per hour of steam on;
	2·26 cubic feet per train-mile;
	1·35 lb. per ton gross per mile;
	9·25 lbs. per lb. coal.

Again, with the special weighted train, the performance stood thus:—

Train, 28 carriages, 203 tons; with engine and tender, 236 tons.

Average speed, excluding stoppages,	30·7 miles per hour.
Gross consumption of coal,	30·5 lbs. per train-mile; or
	·121 lb. per ton gross per train-mile.
Nett consumption of coal, on duty,	915 lbs. per hour steam on;
	28·7 lbs. per train-mile.
	·122 lb. per ton gross per train-mile.
Nett consumption of water, on duty,	150 cubic feet per hour of steam on,
	4·7 cubic feet per train-mile;
	1·08 lb. per ton gross per mile;
	5·87 lbs. per lb. coal.

TABLE No. VII.—OF THE PERFORMANCE OF BEATTIE'S COAL-BURNING PASSENGER-LOCOMOTIVE, "CANUTE," ON THE LONDON AND SOUTH WESTERN RAILWAY, WITH EXPRESS AND MAIL TRAINS, BETWEEN LONDON AND SOUTHAMPTON, IN MARCH AND APRIL, 1856.

Train.			Speed, &c.			Water.			Fuel.										Working Conditions of Engine.			Wind and Weather.
							Nett Consumption.					Nett Consumption, excluding getting up steam, and empty running										
Average Number of Carriages.	Weight of Train (estimated).	Weight of Engine, Tender, and Train.	Average Length of Run between Stopping Stations.	Average Speed, including Stoppages.	Average Speed, excluding Stoppages.	Gross Consumption.	On Duty with Trains.	Per hour Blast on Fire.	Description of Fuel.	Gross Consumption.	Gross per mile.	On Duty with Trains.	Per hour Steam on	Per hour per foot of Grate.	Per mile with Trains.	Per mile per ton Gross.	Water Consumed per Pound of Fuel.	With Tiles, or without Tiles.	Feed-water, average Temperature.	Boiler blown off.	
Carriages.	tons.	tons.	miles.	miles per hour.	miles per hour.	cubic feet.	cubic feet.	cubic feet.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lb.	lbs.				
11	69	102	14·3	30·1	33	384	356	82	Coal	2744	17·4	2411	554	35	15·3	·150	9·25	Tiles.	191°	Blown off twice in 7 trips.	Strong N.E. side wind in 3 trips—calm in 4 trips.[1]
28 Special	203	236	39·4	28·8	30·7	645	626	130	Coal	4685	30·5	4411	915	57	28·7	·122	6·87	Tiles.	212°	Not blown off.	Slight wind.[2]
11	69	102	15·7	29·6	33	481	455	105	Coal	3759	24·0	3416	787	49	21·7	·213	8·31	Tiles.	Cold	Blown off.	Strong side wind.[3]
11·3	70·5	103·5	13·1	30·3	33·3	385	362	85	Coal	3150	20·0	2827	668	42	18·0	·175	8·01	No tiles.	201°	Blown off.	Moderate wind, & slight wind, S.W.[4]
15·4	96·5	129·5	10·5	27·8	31·5	560	530	119	Coal	4537	28·5	4163	933	58	28·4	·20	8·00	No tiles.	Cold	Blown off once in 2 trips.	Brisk wind, S.[5]
10·2	64	97	15·7	32·0	35·3	397	360	87	Coke	3512	22·3	3065	738	46	19·5	·20	7·35	Tiles.	204°	Blown off.	Calm.[6]
10·8	67·5	100·5	15·7	32·0	35·6	407	381	96	Coke	3461	22	3109	787	49	19·7	·197	7·66	No tiles.	200°	Blown off.	Moderate wind, S.W.[7]
14·25	89	122	11·2	28·0	31·5	545	516	116	Coke	4185	26·6	3829	864	54	24·3	·20	8·4	No tiles.	Cold	Blown off.	Moderate side wind, N.E.[8]

Remarks on the Working of the Engine, &c.

[1] Means of seven double trips. Engine in regular working order. No smoke. Consumption of water, 8·5 lbs. per lb. coal, when previously blown off; and 9·5 lbs. when not blown off previously.
[2] One double trip, with special weighted train. No smoke.
[3] Mean of two double trips.
[4] Mean of two double trips. Smoke visible when steam was shut off, and blow-pipe in chimney not in action. Consumption of water respectively 7·74 lbs. and 8·28 lbs. per lb. coal, when previously blown off, and not so.
[5] One double trip. Smoke visible, when there was no blast or blow-pipe in chimney.
[6] One double trip,
[7] One double trip, } Average consumption of water per lb. coke, 7·8 lbs.
[8] One double trip,

Note.—1. The coal used was partly "Griff" (hard), and partly "Stavely" (soft).
2. The area of fire-grate was 16 square feet.
3. The weight of train is estimated from the average weight of the carriages.
4. The results are averaged in all cases from double trips, from London to Southampton and back, 157¾ miles with trains; except with the special weighted train.
5. The ashpan-damper was worked more open with cold water than with heated water.

Thus, in ordinary working, the engine was found to have raised 9·25 lbs. water per lb. coal, the mean of seven trips. But, it appeared that when the boiler was blown off, and so cleaned, previously to running, the apparent evaporation in a day's work was less; and when it was not blown off, it was more. Thus, the apparent average evaporation was only 8·5 lbs. water per lb. coal, when blown off previously, and 9·5 lbs. when not blown off. The excess in the latter case, 12 per cent., is due, probably, to the priming of the comparatively foul water, rendered more likely by the limited steam-room in the boiler; and it may be presumed that, though the consumption of water may have been more, this boiler did not evaporate more than 8·5 lbs. water per pound of coal, on ordinary duty. Again, with cold feed-water, the engine evaporated 8·31 lbs. water per lb. coal, the boiler having been blown off previously. Here it may be remarked, that the ratio of water evaporated to fuel, is not necessarily affected by the feed-water heating apparatus, as this returns the condensed steam, along with the heat derived from it to the water, into the boiler; and by so much a reduced consumption of water from the tender is exhibited, proportional to the reduced consumption of fuel due to the use of the apparatus.

When the tiles were withdrawn from the boiler, the evaporation both with cold and with hot water, was 8 lbs. per lb. coal.

In burning coke as fuel, the tiles were not proved to be of any benefit,—as of course they were not expected to be:—indeed, it seems to have done rather better without them. The mean consumption of water was 100 cubic feet per hour, and 7·8 lbs. per lb. coke, against 82 cubic feet per hour, and 8·5 lbs. per lb. coal; at a greater rate of consumption the evaporative efficiency of the coke was, naturally, less than that of coal, and, at equal rates, it is probable that the results would have proved coke to be equal to coal in evaporative efficiency.

Relative Performance:—Selecting for comparison the cases in which the train averaged about eleven carriages, making, with the engine and tender, about 100 tons gross weight, the relative consumptions of fuel were as follow:—

Conditions.			
Coal, tiles, hot water,..................	·15 lb. per mile per ton gross.		
Coal, no tiles, hot water,..............	·175 lb.	do.	do.
Coal, tiles, cold water,.................	·213 lb.	do.	do.
Coke, tiles, hot water,..................	·20 lb.	do.	do.
Coke, no tiles, hot water,..............	·197 lb.	do.	do.

Again, with trains of fourteen to fifteen carriages, making 120 to 130 tons gross, the relative consumptions are as follow:—

Coal, no tiles, cold water,......................	·20 lb. per mile per ton.	
Coke, no tiles, cold water,.....................	·20 lb.	do.

With a train of twenty-eight carriages, making 236 tons gross, the result is, for

Coal, tiles, hot water,.......................... ·122 lb. per mile per ton.

It appears generally from these data,—

First, that by means of the firetiles, the consumption of coal was reduced 14 per cent., as compared with the boiler without them, with heated feed-water in both cases. With cold feed-water, the comparison of results is not so direct: they are ·213 lb. and ·20 lb. coal per mile per ton, respectively, with and without tiles, the apparent advantage in the latter case being due to the much heavier train.

Second, that the consumption of coal as fuel was 25 per

cent. less than that of coke, for the same duty, with tiles and hot water. But, with tiles for coal, and with cold water in both cases, there is no obvious difference.

Third, that the consumption of coal, without tiles, is 11 per cent. less than that of coke, both with hot water. With cold water, the consumptions are practically the same.

Fourth, touching the economy of heating the feed-water, the consumption of coal with tiles was 30 per cent. less with heated than with cold water. Without tiles, it shows 12½ per cent. less; and the direct advantage would have been greater had the trains been equal. With coke, the advantage of heating the feed-water is proved by the fact, that, drawing the lighter train, the consumption of fuel per ton with hot feed-water, was not greater than in drawing the heavier train with cold feed-water.

From the published experiments of Mr. Fothergill, of Manchester, made towards the end of 1855, on the engines of the London and South Western Railway, the results in Table No. VIII. are derived: showing the performances of the "Ironsides" and the "Canute," coal-burning engines, in regular working order, with feed-water heating apparatus attached; and the "Vesuvius" and the "Frome," coke-burning engines, with cold feed-water:—

TABLE No. VIII.—COMPARATIVE RESULTS OF PERFORMANCE OF COAL-BURNING AND COKE-BURNING ENGINES ON THE LONDON AND SOUTH WESTERN RAILWAY, IN 1855

Name of Engine.	Train.		Average Speed, excluding Stoppages.	Fuel consumed per Train-mile.	Water consumed per lb. Fuel.	Highest Temperature of Feed-water.	Average Weather.
	Average number of Carriages.	Gross Weight of Engine, Tender, and Train.					
COAL-BURNING.	Carriages.	tons.	miles per hour.	lbs. Coal.	lbs.	Fah.	
Ironsides, ...	11·6	...	30·5	17·66	7·36	149°	Calm.
Canute,......	10·1	...	23·5	18·84	7·16	181°	Strong wind.
Do., ...	19·0	170·4	28·4	20·37	8·17	161°	Unfavourable wind.
Do., ...	28·0	235·65	26·9	29·8	9·05	?	Strong head-wind.
COKE-BURNING.				Coke.			
Vesuvius, Frome,....	12·5	...	32·5	20·8	7·52	81°	Light wind.
Vesuvius,...	19·0	170·4	27·2	24·4	8·0	54°	Strong wind.
Do., ...	22·0	189·3	24·7	30·2	7·13	36°	Strong head-wind.

Note.—In the coal-burning engines, the feed-water was heated by the exhaust steam. In the coke-burning engines, it was not.

These results with the coal-burning engines, tally pretty well with those of the Author. The coke-burning engines show a decidedly greater consumption than the coal-burners; but that is explained, not by any superior virtue in the using of coal, but by the heating of the feed-water in the latter class of engines, which might also, of course, have been done in the former class. The water raised per lb. coal varies from 7 lbs. to 9 lbs., and it is singular that the ratio of evaporation increases with the rate of the consumption of coal per mile, contrary to all ordinary experience; whereas it decreases as the consumption of coke rises, consistently with ordinary experience. There can be no particular virtue in the coal-burning engines, which should constitute them exceptional in this respect, to ordinary practice; but it is very likely that, for want of blowing off, impurities had accumulated in the boiler, and primed the water over with the steam,—in greater proportion every succeeding day.

From a statement made by Mr. Beattie,* of the performance of the main-line passenger-engines of the London and South Western Railway, it further appears that the duties of coke-burning and coal-burning engines averaged as follow:—

	Lbs. per mile.		Number of Carriages in Train.
Five coke-burning engines, ...	20·68	...	10·38
Five coal-burning engines, ...	18·92	...	12·22

showing that less coal did more work than coke. Estimating the weight of train at the rate of 6½ tons per carriage, and adding the weight of the engine and tender, 33 tons, the following are the gross loads, and the consumptions of fuel:—

Coke, ...	100·5 tons gross,	...	·206 lb. per mile per ton gross.	
Coal, ...	112·43 do.,	...	·168 lb.	do. do.

showing a saving in weight of 18 per cent. of coal, as compared with coke,—due, not so much to any superior evaporative value, as to the use of the feed-water heating apparatus.

It may be concluded that, on Beattie's system, the complete combustion of coal is practically effected, and that visible smoke may be entirely prevented. The employment of firetiles is attended with material benefit, in economizing coal, by perfecting its combustion, and increasing its evaporative efficiency; and by aiding in the prevention of smoke. The beneficial results of the use of firetiles are, in the opinion of the Author, due mainly to their promoting the mixture of the gases and the air; probably, also, in some degree, to their elevating the temperature of the air and other gases. The duty realizable from coal is greater than that which is yielded by coke burnt in the same engine, the "Canute:"—owing to the unfavourably large grate and capacious firebox of this engine, which are not suited for developing the best performance of coke as fuel. The coal-burner appears to require a large grate, and a large capacity of firebox; but the coke-burner requires, for the greatest efficiency of the fuel, a moderate grate and a moderate capacity. Accordingly, from Mr. Fothergill's and Mr. Beattie's observations, it was shown that the coke-burning engines,—that is to say, the engines adapted for burning coke,—were as efficient as the coal-burning engines, on the same line, per lb. of fuel, allowance being made for the superior arrangements in the latter engines, for heating the feed-water. The various influence of hot and cold feed-water on the results is remarkable:—benefits which are very apparent, in conjunction with hot water, cease to be so, or are so to a less extent, with cold water. Thus, 14 per cent. less fuel was consumed, with the use of the firetiles, than without them, when the feed-water was heated throughout. But when the feed-water was cold, the consumption of fuel per ton gross was sensibly the same with and without tiles; though some advantage was manifested indirectly in the circumstance of the train taken with the tiles having been lighter than that taken without them. The less apparent benefits arising from changes of condition, with the cold water, is most probably to be ascribed to the necessity for working the engine with the dampers very open, when the water was cold, and to the fire being thus placed so far beyond the reach of delicate management. The particular question of heating the feed-water follows for discussion in another chapter.

* *Minutes of Proceedings of the Institution of Civil Engineers*, Session 1856–57.

CHAPTER IX.

RESULTS OF PRACTICE IN COAL-BURNING—(*Continued*).

Cudworth's Engine, South-Eastern Railway.—The Author has had frequent opportunities of observing the working of Mr. Cudworth's arrangement of boiler, with elongated firebox and inclined grate, represented by Fig. 48, page *28:—the distinctive principle of which is, to feed the fuel at the firedoor, and let it progress forward as it burns, providing a long run for the combustion of the gases driven off from the fresh fuel. The results obtained by the Author coincide with Mr. Cudworth's, of which Table No. IX. contains a condensed abstract.

TABLE No. IX.—OF THE PERFORMANCE OF CUDWORTH'S COAL-BURNING LOCOMOTIVE-ENGINES, ON THE SOUTH-EASTERN RAILWAY, WITH EXPRESS AND ORDINARY TRAINS, ON THE MAIN LINE, AND THE BRANCHES, IN 1857.

No. of Engine.	Date.	Train.			Speed, &c.			Water.		Fuel.										Weather, &c.
		Average Number of Carriages.	Weight of Train.	Weight of Engine, Tender, and Train.	Average Length of Run between Stopping Stations.	Average Speed, including Stoppages.	Average Speed, excluding Stoppages.	Gross Consumption.	Per hour Blast on Fire.	Description of Fuel.	Gross Consumption.	Gross per mile.	Nett Consumption, excluding getting up Steam. On Duty with Trains.	Per hour Blast on Fire, or Steam on.	Per hour per foot of Grate.	Per mile.	Per mile per ton gross.	Water Consumed per lb. of Fuel, allowing 1½ cwt. to get up Steam.	Average Pressure per square inch, in Boiler.	
	1857.	Carriages.	tons.	tons.	miles.	miles per hour.	miles per hour.	cubic feet.	cubic feet.		lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lb.	lbs.	lbs.	
No. 142, 'Folkestone' class. Between Ashford and London, 67 miles.	Oct. Up.	18·0	90	140	4·2	19·7	25·1	264	120	Hartley coal.	2045	30·5	1905	882	59	29·5	·21	8·5	92	Calm, light wind.[1]
	" Down.	10·3	51·5	101·5	20·3	33·7	36·2	191	111	do.	1629	24·3	1489	871	58	23·3	·23	8·0	85	Calm, light wind.[2]
	Oct., Nov. Up.	14·2	71·0	121	3·8	20·7	26·4	237	135	Coking coal.	1769	26·4	1629	927	62	25·4	·21	9·0	81	Calm, strong wind S.E.[3]
	" " Down.	13·5	67·5	117·5	22·0	51·3	33·6	222	119	do.	1860	27·8	1729	929	62	26·8	·22	8·2	78	Calm, fair.[4]
	Nov. Up.	12·5	62·5	112·5	4·6	21·2	25·3	211	118	do.	1538	23·0	1398	782	52	22·0	·20	9·4	82	Calm, showery.[5]
	" Down.	10·5	52·5	102·5	10·1	34·2	38·0	201	141	do.	1617	24·1	1477	1096	73	23·1	·22	8·5	91	Calm, foggy.[6]
	1854, July. Double trips.	15·0	75·0	115	8·0	34·7	36·2	411	116	Coke.	3189	24·0	2900	819	53	23·0	·20	8·2	—	Calm, light wind S., strong wind W.[7]
No. 105.	1857, May. Ramsgate and Hastings Branches, 120 m. per day.	5·33	26·6	56·6	4·6	24·5	27·4	251	92	Coke.	1747	14·9	1607	557	60	13·7	·24	6·8	85	Fine, light wind.[8]
No. 6.		5·85	29·2	59·2	4·6	25·1	28·2	276	105	do.	1957	16·3	1817	695	66	15·1	·25	9·2	85	Fine, light wind.[8]
No. 58.		6·16	30·8	60·8	4·4	24·3	27·3	275	102	Hartley coal.	2151	18·0	2011	750	77	16·8	·27	8·5	85	Fine, light rain.[8]
Do.		4·55	22·7	52·7	4·6	23·0	27·4	248	94	Coking coal.	1695	14·1	1555	545	56	13·0	·26	10·0	85	Fine, light wind.[8]
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21

[1] Mean of three up trips. Cold feed-water.
[2] Do. three down trips. Cold feed-water. In the last trip, the coal was small and dusty, inferior in duty.
[3] Do. two up trips. Cold feed-water.
[4] Do. two down trips. Cold feed-water. In last trip, coal small and inferior.
[5] Do. two up trips. Hot feed-water, heated by blowing waste steam into tender.
[6] Mean of two down trips. Hot feed-water.
[7] Do. two double trips. Cold feed-water.
[8] Cold feed-water to all these trials.
Area of fire-grate, No. 142, 15 square feet.
Area of fire-grate, No. 105, 9·75 square feet.
Do., No. 6, 10·5 do.
Do., No. 58, 9·75 do.

Note.—1. The time of the steam on the piston, or blast on fire, has been estimated by deducting five minutes per stoppage from the time on duty with train.

2. The gross consumptions of water and fuel, cols. 9 and 12, comprehend the entire consumptions on and off duty. The empty mileage of engines was very short. In finding the fuel consumed, the good coke left in the firebox was allowed for.

3. An allowance of 1½ cwt. of fuel has been deducted for getting up steam, in estimating the nett consumption, col. 14, and the ratio of water to fuel consumed, col. 19.

4. No. 142 engine, on the main line, with Hartley coal, made steam freely; the fire was seldom stirred; no smoke, except a little occasionally when stoking. The blow-pipe required to be very little opened to prevent smoke at stations. In one down trip, the coal was small and dusty, and raised only 7 lbs. of water per lb. coal, average pressure 78 lbs.

5. No. 142 engine, with coking coal, made steam with difficulty, required frequent stirring, when considerable smoke was made. Blow-pipe fully opened at stations. In one down trip, lost twenty-eight minutes; coals small, and continually stirred, making much smoke. With heated feed-water, made sufficient steam; required stirring before stoking, considerable smoke.

Averaging the main-line performances with No. 142, the following results with coal as fuel, are derived:—

Engine and tender,...................	50 tons weight.
Train, 13·16 carriages,..................	65·8 tons weight.
Engine, tender, and train,.............	115·8 tons gross weight.
Average speed, excluding stoppages,..	30·8 miles per hour.
Gross consumption of coal,............	26 lbs. per train-mile;
	·225 lb. per ton gross per mile.
Nett consumption of coal, on duty,..	915 lbs. per hour steam on;
	25 lbs. per mile;
	·215 lb. per ton gross per mile.
Consumption of water,..................	124 cubic feet per hour steam on;
	3·3 do. per mile;
	1·78 lb. per ton gross per mile.
	8·6 lbs. per lb. coal.

Doing the same duty with coke, the engine, in its original condition, consumed 24 lbs. gross per mile, or 23 lbs. nett, equal to ·20 lb. per ton gross per mile.

On the branch lines, the relative performance of lighter engines was equally good. With average trains of about 5½ carriages, the average consumptions with coke and with coal were respectively ·245 lb. and ·26 lb per mile.

The evaporative power of the coal was remarkably good, amounting in one case to 10 lbs. water per lb. coal, and with No. 142, averaging 8·6 lbs. per lb. coal, against 8·2 lbs. per lb. of coke by the same engine previous to alteration for burning coal.

In the use of the inclined grate, frequent firing is needful, as the fuel is replenished at the entrance only. With steam coal which required very little stirring, smoke was successfully prevented; with coking coal, when stirred, considerable smoke was discharged.

Since the foregoing results of the working of Mr. Cudworth's engine were obtained, the fire-grate of the engine has been further enlarged, and inclined, to adapt it still better for the consumption of bituminous coal. This it does efficiently and economically, with very little stirring of the fire, keeping up steam abundantly at 110 lbs. to 120 lbs., and without smoke. The grate-bars are laid closely, with very narrow air-spaces, and a tightly-fitted ashpan and damper. The following comparative statement of the train-mileage and consumption of fuel of No. 142 coal-burning engine, and of five coke-burning

engines of the same general dimensions, on the same routine of duty, shows that the performance of No. 142, with coal, is superior to that of the best of the other engines with coke, and much better than the average of them:—

TABLE No. X.—TRAIN-MILEAGE AND CONSUMPTION OF FUEL OF COAL-BURNING AND COKE-BURNING ENGINES, ON THE SOUTH-EASTERN RAILWAY, WITH EXPRESS AND ORDINARY TRAINS, FOR 36 WEEKS, FROM MARCH 12 TO NOV. 20, 1858.

ENGINE.	Train-Miles run.	Fuel Consumed.	
		Total.	Per Train-Mile.
	Miles.	Cwts. Coal.	Lbs. Coal.
(COAL-BURNER.) No. 142	23,462	4,366	20·84
(COKE-BURNERS.) No. 36, No. 134, No. 139, No. 140, No. 147	89,968	Coke. 19,974	Coke. 24·24
The best of the above—No. 36	28,466	Coke. 5,555	Coke. 21·86

Douglas's Engine, Birkenhead, Lancashire, and Cheshire Junction Railway.—Thirty of the engines on this line, passenger and goods, are fitted with a deflecting plate in the doorway, for the admission and downward draft of air upon the fuel. This plan, with others on the same principle brought out about the same time, in June, 1858, will receive further explanation and illustration in a supplementary chapter. Meantime, the following results of the working of these engines for the fortnight ending January 5, 1859, communicated by Mr. Douglas, may be placed on record:—

TABLE No. XI.—RESULTS OF PERFORMANCE OF DOUGLAS'S COAL-BURNING LOCOMOTIVE-ENGINES, ON THE BIRKENHEAD, LANCASHIRE, AND CHESHIRE JUNCTION RAILWAY, FOR FORTNIGHT ENDING JANUARY 5, 1859.

ENGINES.	Twelve Passenger Engines.	Fourteen Goods Engines.
Miles run by engines, miles,	10,970	9,192
Fuel consumed:—		
Best pure coke, cwts.	53	128
Tryddyn North Wales, Hand-picked hard steam-coal, cwts.	2,732	4,095
Total fuel per engine-mile,	28·4 lbs.	51·4 lbs.
Average train, vehicles,	7	32
Nett load, tons,	—	250

CHAPTER X.

RESULTS OF PRACTICE IN COAL-BURNING—(*Continued*).

D. K. Clark's Method of Steam-inducted Air-currents.—This plan of burning coal without smoke, as adapted to the locomotive-boiler, was tried first on the North London Railway, upon No. 12 tank-engine, in January, 1858. The firebox was 3 feet 6 inches wide, and 3 feet long; four tubular openings, in a row, 1¼ inch diameter, were made through one side of the firebox only, the other side being blocked by a coke-box. Air was admitted through these openings, and delivered over the fuel, and forcibly inducted when necessary by means of four jets of steam from the boiler, $\frac{1}{16}$ inch in diameter, pointed into the openings. By these means, smoke was effectually prevented, in using hard coal, smoky enough in itself. The chimney was comparatively wide, being 15 inches in diameter, and the firebox small; and the result was that all the products of combustion were carried off, and smoke was banished from the chimney-top, by the natural draft of the boiler, when the steam was shut off, and without the aid of the blow-pipe in the chimney! This is the first instance on record, in which coal-smoke could be effectually prevented in a locomotive-boiler without the assistance of that powerful auxiliary. As an experiment, to test the capacity of the engine to consume its own smoke, by means of the steam-inducted currents of air, a few shovelsful of dross were thrown upon the fire, which immediately discharged a dense black cloud of smoke, when the steam was not in action; but when the steam was turned on, and powerful currents of air projected into the atmosphere of the firebox, the black cloud speedily rolled off, and, without any assistance from the blow-pipe, left the chimney-top as clear as the sky. When the steam was temporarily shut off, the cloud of dark smoke reappeared. As the traffic of the North London Railway is short and intermittent, particulars of the working of this engine were not taken.

The second application of the method of steam-inducted air-currents was made to No. 64 passenger-engine, on the Eastern Counties Railway, and was put to work in April, 1858. The firebox of this engine is 4 feet long, and 3 feet 6 inches wide, inside, and the chimney is only 13 inches in diameter. Two rows of 2-inch tubular openings, at different levels, were made through each side of the firebox, four openings in the row on one side, and three on the other, to alternate with those opposite. Two rows of $\frac{3}{16}$-inch jets of steam were applied on each side, to correspond with the openings; but it was found that, practically, the lower rows were sufficient. The two upper rows were filled up, and the lower jet-nozzles were enlarged to $\frac{3}{16}$ inch, or about $\frac{1}{5}$ inch diameter; and, with these dimensions, the engine works with efficiency in burning coal, keeping up steam, and preventing smoke,—

TABLE No. XII.—COMPARATIVE RESULTS OF THE USE OF COKE AND COAL WITH D. K. CLARK'S APPARATUS, ON THE EASTERN COUNTIES RAILWAY, 1858.

	BURNING COAL.	BURNING COKE.	
Engine and Tender	36 tons	36 tons	Weight.
Train	9·0	8·72	Carriages.
Weight of Train	63 tons	61 tons	Weight.
Engine, Tender, and Train	99 tons	97 tons	Gross Weight.
Average distance between Stopping Stations	5·5 miles	5·5 miles	Miles.
Average Speed, including Stoppages	23 do.	23 do.	Miles per hour.
Do., excluding do.	26 do.	26 do.	do.
Gross Consumption of Fuel	29·6 lbs.	27 lbs.	Per train-mile.
Do.	·30 lb.	·28 lb.	Per ton gross per mile.
Nett Consumption of Fuel, on duty	880 lbs.	800 lbs.	Per hour steam on.
Do.	28·2 lbs.	25·6 lbs.	Per train-mile.
Do.	·285 lb.	·264 lb.	Per ton gross per train-mile.
Gross Consumption of Water	3·37 cubic ft.	3·23 cubic ft.	Per train-mile.
Nett Consumption of Water, on duty	100 do.	96 do.	Per hour steam on.
Do.	3·22 do.	3·08 do.	Per train-mile.
Do.	2·03 lbs.	2·0 lbs.	Per ton gross per mile.
Gross Consumption of Water per lb. of fuel (setting off 1½ cwt. of fuel per day, for getting up steam)	7·36 lbs.	7·76 lbs.	Per lb. of fuel.
Average Weather	Strong Side Wind. Wet.	Slight Wind. Dry.	

taking the London, Norwich, and Ipswich trains in due course, and keeping time. Though the engine is rather heavy on the fuel, with so large a firebox, the results of her performance may here be stated, in Table No. XII., as carefully observed by the Author; and they are put forward, not as finished results, but only as the results of what may be called the first rude practical application of the method. The arrangement is illustrated by Figs. 54, 55, page *30.

In comparing these results with coal, and with coke, it is to be observed that the weather was comparatively unfavourable, and the average train rather heavier, whilst burning coal.

Second, that the greater proportion of coal was soft Stanley, and the remainder hard Portland, and that, under these circumstances, 2¼ lbs. per inch, or about 10 per cent., more coal than coke was consumed. Per ton gross, the extra consumption of coal was only 7 per cent., as compared with coke.

Third, the evaporative efficiency of the coal was as 7·36 lbs. to 7·76 lbs., or only 5 per cent. short of that of the coke.

Fourth, the air-openings were closed when coke was burned; and steam was kept up equally well and easily with coal as with coke, without any extra management of the fire; and good time was kept every day.

It is further to be remarked, that, on account of wind and weather, the duty being heavier whilst burning coal than coke,—as is obvious from the fact of the greater mileage consumption of water in the former case,—the less evaporative efficiency of the coal is accounted for. And, as the air-openings through the sides of the firebox were occasionally stopped by the fuel, there is no doubt that, by increasing the number of the air-openings, and otherwise improving the details, a performance, at least equally effective, may be had from coal as fuel, as from coke. Lastly, it is to be borne in mind, that the question is not, as between one engine burning coal, and another engine burning coke, but as between the use of coal and of coke in the same engine.

The apparatus was next applied to a goods-engine, No. 305, on the same line, and the engine was put to work in November, 1858, using coal only as fuel. The firebox was 3 feet 6 inches square; it was fitted with four conical openings on each side, 2 inches diameter at the firebox, and 2¾ inches at the outside. As the hind-wheels reached partially along the sides of the firebox, the openings were placed chiefly in the forward part, to clear the wheels, and the jets of steam were angled fore and aft, to rake the entire area of the firebox. They were also inclined downwards at an angle of 1 in 4, not as a necessity, but as an experiment, to show how the inducted currents could reach the surface of the fuel at varying levels. The results obtained are satisfactory:—smoke is effectually prevented, the air is equally distributed, the angling of the nozzles sufficing to effect an equal distribution; and it appears that the consumption of fuel, using coal only, does not exceed the previous consumption with coke, being in both cases about 50 lbs. per mile.

It is to be presumed, that the consumption of coal would be still less if the air-openings were fitted with dampers, to regulate the supply of air. It appears, also, to follow, from the experience of the method of steam-inducted air-currents, that the proportion of steam consumed in the process is scarcely appreciable; at all events, it is not important. Moreover, this method is distinguished from all others, in its capability for preventing smoke without the aid of the blow-pipe in the chimney, when the latter is sufficiently wide to induce the needful draft:—to be accounted for, it would appear, by the accomplishment of complete combustion within the firebox. The blow-pipe is nevertheless, of course, a convenient auxiliary, in drawing off the products of combustion which necessarily accumulate in the firebox, and which would otherwise be likely to cause a downward reflux through the grate, with other inconveniences. It is not maintained that, in the particular instance of No. 64, on the Eastern Counties Railway, this independent action of the inducted currents was entirely attained to, as they were not sufficiently numerous, and the chimney was small. Nevertheless, in that engine, the smoke has been very much reduced in density by the unaided action of these currents; and in No. 12 on the North London line, it has been completely reduced, without the aid of the blow-pipe. In a small stationary boiler on the locomotive plan, the same result has been accomplished.

CHAPTER XI.

Solution of the Problem of the Complete and Effective Combustion of Coal in Locomotives.

It has not been attempted, in the few foregoing chapters, to account for everything that has been done in locomotives for the purpose of consuming coal without smoke; the intention has been to show the general direction in which engineers have looked for the means of insuring complete combustion. There is one little feature, of considerable importance, common to all,—the steam-blowpipe or auxiliary jet in the chimney,—which is made use of for the purpose of continuing the draft of the furnace, when the powerful artificial stimulus of the blast is at intervals suspended. The action of this smoke-annihilator is well worthy of study, and it is a question of directly practical interest in what way the blow-pipe operates thus serviceably. Looking into an ordinary firebox, at rest, under the action of the blow-pipe, smoke may be perceived in the firebox, wending its way into the tubes, which becomes totally invisible at the top of the chimney. By what process is this visible smoke made invisible? It seems to be by absorption, or precipitation, or a little of each, by the steam from the blow-pipe:—the jet of steam "paints the smoke." Imperfect though such a mode of banishing smoke may appear, it is nevertheless true that every one of the coal-burning contrivances falls back upon the blow-pipe, for the means of consummating the extinction of smoke. The action of the steam-blast in destroying visible smoke, while the engine is at work, is apparent to the most ordinary observer, inasmuch as the discharge from the chimney, which may be clear and colourless when the blast is on, may become densely brown or black when the blast is off, and may only be mitigated by a discharge of steam from the blow-pipe. That steam possesses a considerable power of precipitating smoke particles, may readily enough be observed over an

ordinary domestic fire, by directing the steam spouting from a kettle into the ascending smoke. It is found to banish the smoke in a greater or less degree,—certainly not by any act of combustion or other chemical process, but by simple physical action. And, it is in virtue of the same faculty of absorbing or precipitating smoke-particles, that certain processes for preventing smoke operate by passing the smoke into intimate contact with water. It is found, similarly, that smoke from stationary chimneys is subdued or mitigated by discharging the exhaust steam into the chimney. Of course, the action of exhaust steam, so directed, in accelerating the draft, and thus in another way diminishing smoke, is distinguishable from its action as a precipitant or absorbent; but, in many cases, doubtless, the prevention or reduction of smoke by the agency of steam in the chimney, is due mainly to its operation in the latter capacity.

It cannot properly, therefore, be assumed that combustion is in every case complete when smoke is prevented by the agency of steam in the chimney:—whether the engine be running under the blast, or standing under the blowpipe. This is a fair subject for practical investigation; meantime, one conclusion of practical value may be drawn from the general experience of the smoke-preventing agency of steam, and that is, that we have to guard against being misled by appearances, and should not be diverted from the accomplishment of the main object,—the thorough combustion of coal by ample admission and intimate mixture of air above the fuel, and amongst the smoke.

It may be added, that where pure steam is discharged upon or over the surface of the fuel, whilst it operates favourably in preventing or reducing smoke, it also damps the fire, and retards combustion; at least, such is the tendency of this mode of using steam, so far as it has come within the Author's experience,—in whatever way it is introduced. Consequently, modes of smoke-prevention by the agency of pure steam, over or upon the fuel, are usually attended by a difficulty in making steam, and an excessive expenditure of fuel.

The necessity for admitting a supply of air above the fuel is understood and acknowledged by all,—whether it be through the grate or otherwise. When the grate is very large, and a thin fire maintained, the needful supply of air may be taken almost entirely through the grate. It is, however, indispensable to this mode of managing the fire, that the fuel should be carefully supplied at short intervals, and in small quantities, uniformly distributed:—in recognition of the principle that the more nearly uniform the supply of fuel, the more so, also, is the generation of combustible gases, and the more probable, accordingly, is the combustion of these gases, and the prevention of smoke. With inclined grates, of course, the fuel is only deposited near the entrance, and finds its way down by gravitation; and their greater ease of management, in this respect, compared with ordinary level grates, mainly constitutes their superiority to these:—precisely as Juckes' furnace, fed continuously at the entrance, is superior to ordinary stationary furnaces. With small or moderate-sized level grates, a coal-fire demands still greater care than with larger grates, where smoke is to be prevented by air from the grate:—the firing must be still more frequent; and as the door, of course, is more frequently opened, another evil is incurred,—the admission of a large proportion of cold air into the firebox, most of which passes off unburnt through the tubes, chilling the boiler, and checking the production of steam. Such evils are very much reduced in magnitude by the simple process of admitting fresh air for the combustion of the gases, otherwise than through the fuel,—in greater or less proportions, according as it may be utilized; and, as this independent admission of air is a very simple process, it is not worth anybody's while to endeavour to dispense with it.

It may, then, be adopted as an axiom in locomotive practice, that an independent supply of air should be admitted above the fuel, for the conversion of the combustible gases. Further, the air so admitted must be thoroughly mixed with the gases. Length of run promotes the mixture, and in Mr. Beattie's boiler, the mixture is further advanced by the interposition of firetiles. Mr. Yarrow's brick arch operates beneficially in the same way,—doubling the run, and promoting the mixture. Douglas's baffle-plate hung inside the firebox, against the doorway, and Lees' hood on the door,—similar to each other in their mode of operation, and both of them ingenious,—operate reversely, and with considerable success, by inverting the draft of the air admitted through the doorway, and directing it over the surface of the fuel. Both these plans, however, involve careful management of the fire,—thin and frequent firing, and incandescent fuel at stations; and a cautious and regulated admission of air through the doorway, lest it should be admitted in too great volume, and be imperfectly mixed,—letting down the steam, and wasting the fuel. They also require very powerful blow-pipes in the chimney. To insure the prompt and effective mixture of the air and gases, the air should be admitted at the surface of the fuel; and the nearer to the origin of the gases, the better is the result.

But, the ample admission and intimate intermixture of air with the gases above the fuel, must be effected in conjunction with a sufficiently high temperature; and this condition has led to the adoption of various modes of heating the air, or the gases, or both, prior to, or at the time of mixture. Mr. M'Connell suggested the use of an air-chamber within the smokebox, in which air was designed to be heated, and led into the firebox through tubes. Mr. Wilson, and Mr. D. Gooch, conduct air from the front, through the smokebox, and the boiler, by a number of the flue-tubes, and these also partially heat the air on its way to the firebox,—letting down the steam, of course, in a proportional degree. Mr. John Gray established a coke-fire on a supplementary grate, as a reservoir of heat within the fire-chambers, and Mr. Beattie embodies his reservoir in faggots of firebrick; and others attempt to heat the air by conducting it partially over the surface of the firebox-shell. Expedients of this class, operate, no doubt, in some degree advantageously; but in the adoption of such supplementary contrivances, it appears to have been overlooked that there is abundance of heat within the incandescent fuel itself, to supply the demand for temperature. We are of opinion with Mr. C. W. Williams that the combustible gases themselves, when taken at their origin, are, in general, sufficiently high in temperature to sustain combustion with cold air: and it

is demonstrable in practice, that this may be done in a simple and natural manner, by effecting the needful preliminary process of heating the air at or near the surface of the fuel, whence the gases emerge at their highest temperature, and where the radiant heat from the fuel is at its maximum intensity. In boilers with internal furnaces, more than in others which have their furnaces surrounded with brick, this immediate process of mixture and combustion is needful, inasmuch as the absorption of heat by the surrounding surfaces, and the degradation of temperature in the atmosphere of the furnace more promptly and decisively take place in the former than in the latter.

The problem of the direct and efficient combustion of coal, in the locomotive-boiler, appears, then, to be brought into a narrow compass, and resolves itself into the following conditions:—THE IMMEDIATE AND THOROUGH INTERMIXTURE OF A PLENTIFUL BUT REGULATED SUPPLY OF AIR, WITH THE ASCENDING SMOKE OR COMBUSTIBLE GASES, AT OR NEAR TO THE SURFACE OF THE FUEL.

The plan which most simply and efficiently works out these conditions in practice, so far as the agency of the ordinary draft is available, consists of rows of tubular openings through the walls of the firebox, at the level of the fuel:—they conduct streams of air right into the firebox, at the proper place, meeting the ascending currents of combustible gases at right angles, impinging upon, and commingling with them. Practically, the level of the fuel varies with the state of the fire; but, if the air-openings be fixed just at the highest level of the fuel, they continue serviceable and efficient, within the limits of good practice. Good results have been had from the use of seven 2-inch tubular openings through each side of the firebox; and taking that number for a fire-grate of, say, 12 square feet area, they give for the two sides 45 square inches sectional area of air-way, or about 4 square inches per square foot of grate. With dampers or slides, the openings may be contracted according to the requirements.

For fireboxes of limited length and breadth, and great depth, it is expedient to incline the air-openings, so as to direct the air-currents downwards upon the fuel, at whatever level the surface of the fuel may be.

So much for what may be done by means of the natural draft, aided, if need be, by the blow-pipe in the chimney. It is not perfect, but is good as far as it goes; it wants range of power, to overtake the extremes of intense ignition and rapid generation of smoke-making gases, immediately after the steam is shut off, or when fresh fuel is added; and to suit itself also to the quiet state of the fire when the glow and excitement subside, as well as to all the varying conditions of a locomotive-furnace. The means of vastly extending the range, volume, and power of the air-currents, and of delicately adjusting them to the wants of the furnace, are supplied by the instrumentality of the jets of steam employed by Mr. D. K. Clark, as means of inducting and accelerating currents of air, according to his method of steam-induction. The steam-nozzles, with the air-tubes towards which they are pointed, are like so many miniature blast-pipes and chimneys, turned into the firebox, and they possess relatively the same power of urging and creating draft. By his method of steam-induction, Mr. Clark delivers the air-currents with such precision and velocity as to sweep the whole surface of the fuel, and forcibly to distribute the air amongst the gases. Of the virtue of forcible impingement in promoting and accelerating combustion, numerous examples occur in ordinary practice. So it is that the ordinary bellows blow up a house-fire; and if the upper front of the fireplace be closed with a sheet of paper, to direct the draft through the ribs upon the fuel and combustible gases, the air-currents so deflected and forcibly impinged upon them, consume the gases and prevent smoke. The contracted neck of the glass tube of a moderator lamp, adjusted so as to impinge the ascending air within the tube upon the upper part of the flame, increases its volume and brightness. In Mr. Beattie's boiler, the smoke-consuming process is to a great extent based on the same principle of forcible impingement of the air and gases amongst each other, as they roll against the firetiles and diaphragms. By Mr. Clark's process, the entire operation is consummated within the four walls of an ordinary firebox:—the inducted currents sweep up the gases and forcibly mix with them, and, if judiciously arranged, they may be thrown together, and further intermixed with each other.

Though, in the method of steam-induction, the steam is treated simply as a vehicle for air, it may be remarked that the character of the steam, when thus associated with air, is entirely changed in its action on the fire, as compared with pure steam. Its effect is invariably to brighten the fuel and inflame the surface, so that active combustion of the solid fuel proceeds above, as well as below. The inducted currents dash across the surface, like flashing cones of flame, and they groove out the fuel that lies in their way. The production of steam, also, is invariably increased.

In practical working, it is not usually necessary to put the steam-jets in action when the engine is at work, if the air-openings be sufficiently numerous, as the action of the blast alone draws a large supply of air through them into the firebox. At times, however, when the fire is stirred, or fresh fuel added, while running, the jets may be turned on with advantage, to prevent smoke and perfect combustion. But the time at which the full inducting power of the jets of steam are in demand, is immediately on the steam being shut off, when the engine is drawing up to a station or otherwise. Then, the heat in the firebox is fierce, and there is an extensive distillation of combustible gases, which are discharged as smoke from the chimney, unless met and consumed by the inducted currents above the fuel. The intenseness of the heat, of course, subsides rapidly, and the jets may be moderated as desired, and continued in action till the engine is again in motion.

Thus it has been shown in what direction a general solution of the problem of the combustion of coal without smoke in ordinary locomotive-boilers, is to be sought:—namely, by the construction of a sufficient number of tubular openings through the walls of the firebox, ranged at the level of the fuel, and equally distributed, for the admission of air over and close to the surface. This, or an analogous arrangement, must form the basis of action.

The indraught of air into the firebox may, if desired, be regulated by the use of slides or dampers over the air-openings. But, by so limiting the number of air-openings,

and consequently the supply of air, as to prevent any material excess of supply when the fire is in ordinary condition, the dampers may, perhaps, in practice, be dispensed with, without prejudice to the economy of fuel. And, inasmuch as, in ordinary locomotive-working, the fire is unavoidably subject to extremely various changes:—dull, for example, and gas-evolving, when the blast is on; or bright and intense, and profusely distilling combustible gases, when the blast is off;—it is evident that the air-channels do not and cannot at all times supply the requisite quantity of air for perfecting the combustion, and with the requisite velocity of impingement for accelerating combustion. The desideratum suggested by this deficiency, is supplied, in what is obviously the simplest, most direct, and most effective manner, by the method of steam-inducted air-currents.

PHYSIOLOGY OF THE BOILER:—HEAT-TRAPS, STEAM, &c.

CHAPTER XII.

Heat-Traps.

There is one principle of construction for the conservation and utilization of heat, which has been almost totally neglected in locomotive practice; and that is, the descending flue. The hot products of combustion rise continuously on their way from the fire-grate to the chimney; at no point do they descend. The annexed Fig. 56 illustrates in outline the course of the draft: it

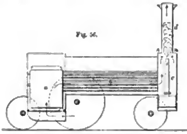


Diagram to show the Mechanical Action of the Blast.

commences at the lowest point, the ashpan, and passes up through the grate into the firebox *a*; upward it proceeds into the tubes *b*, horizontally to the smoke-box *c*, and thence upwards into the chimney *d*. Now, this is a grand mistake. The heat must be trapped: the hot gases ought to be intercepted, and detained until their surplus heat is absorbed through the heating surface; and the exit from the trap must be at the lowest practicable level, whence the lower and colder strata of gases alone should pass off to the chimney, leaving the superincumbent and hotter strata of gases to deliver their heat to the water in the due course of absorption. This principle of the descending flue or heat-trap is appreciated in many varieties of furnace construction, and with material advantage in efficiency and economy. It reverses the conditions of the existing locomotive-boiler; in the latter, the hotter gases naturally ascend, and are drawn off in preference to the colder gases; in the former, the gases of combustion are trapped at the lowest level, drawing off the colder gases in preference to the hotter. The superiority of the system of the heat-trap, or descending flue, over the prevailing system of the continuously ascending flue, is placed by the results of general practice beyond the range of speculation, and it is now for engineers to apply it in the best manner to locomotives.

The heat-trap is partially embodied in the venetian damper employed by Gooch, and applied against the ends of the tubes in the smoke-box. The damper is, in ordinary circumstances, allowed to hang freely over the tube-ends, flapping open and shut, in sympathy with the blast-pipe; and, in so far as the flue-way through the upper tubes is thus contracted, the gases are driven to find their way through the lower tubes, and the function of the tubes beneficially equalized. The same distributive function is partially discharged by ferules in the tubes at the smoke-box end; as these, partially closing the egress from the tubes, send the hot gases to find their way out further down. This they do in comparison with the open tube-ends, adopted in many engines, in which ferules are dispensed with, and the smoke passes freely away. The advantages of the clear tube consist in the superior draft so obtained, and the greater facility for cleaning the tubes; and it is curious to remark the direct contrariety of practice, in the feruled and blinded tube, and the unferuled, uninterrupted tube. One wants a free draft, and a free circulation of heat through the engine; another, having draft, wants to economize. There is no doubt that, by a judicious combination of details, abundance of draft, or, more properly, abundance of steam, may be had, consistently with the best arrangements for trapping the heat. The principle of the heat-trap has been, we believe, applied in another form, by projecting the chimney down into the smoke-box, and reducing the height of the blast-pipe, thus instituting a descending current from the upper flue-tubes. The benefit derivable from this plan has, however, been ascribed to the increased length of chimney, in forgetfulness of the fact that the power of the natural draft is measured simply by the height of the top of the chimney above the fire-grate.

Heat-traps are developed in another way by Mr. Joseph Barrans, in his "cup-surface boiler," having cups or chambers in the four walls of the firebox, projected into the water-spaces, and open to the firebox. Several boilers so furnished have been constructed for stationary uses, and have yielded good results, due, no doubt, to the detention of the hot gases in the cups, as well as to the actual increase of surface.

But, the contrivances we have just referred to, are rudimentary and partial. The principle of the heat-trap and descending flue remains to be fully developed, so as to flood the entire heating surface with heat as in a bath. This may be done variously: by a downward extension of the chimney, as already referred to; but, more perfectly, by the insertion of a diaphragm across the smoke-

box, parallel to the tube-plate, tightly fitted to the top and sides, and open at the lower edge only, for the exit of the smoke towards the chimney. The idea may easily be extended, so as to embrace the cylinders within the scope of the draft, and superheat them.* The diaphragm would, of course, be moveable, to give access to the tubes. The bath might be extended along the barrel, within an outer sheath, which has already been done in some form in agricultural practice. Mr. C. W. Williams has obtained very remarkable economical results in the more thorough absorption of heat by baffling or undulating the currents of heated gases in tubes.

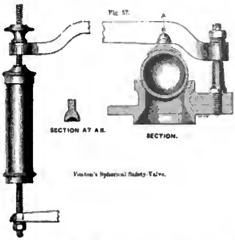
The principle of the descending flue was advantageously embodied by the Earl of Dundonald in his tubular marine boilers, in what he calls "the Economical Heat-trap." The tubes are arranged vertically in a chamber, and contain water, the fire playing around them; the heat-trap is an inverted bridge, inclosing the hot gases, and permitting only the coolest of the smoke to escape. The results of comparative trials made at Woolwich Dockyard, in 1844, with Lord Dundonald's boiler, and the ordinary locomotive-boiler then in use for marine purposes, showed, according to the accounts published, that, in efficiency and economy, Dundonald's boiler was above 40 per cent. superior to the others.† Of course, we quote the results as we read them, and only now refer to them in confirmation of the anticipated value of the "Heat-trap" applied to locomotive-boilers.

CHAPTER XIII.

Safety-Valves.

The ordinary disc-valve, with a lever and spring-balance, is not a satisfactory job; because it is not capable of letting off steam of surplus pressure with sufficient rapidity, to limit the excess of pressure within a moderate degree. A lever is, at least, an imperfection: it binds fast at one end, and yields only at the other end, the farthest from the valve; the greater the leverage the less efficiently does the valve act. On the contrary, the less the leverage, the more prompt is the action, and the less is the permissible excess of pressure. Direct-action safety-valves are the best of all, and, there is no doubt, will supersede the lever-valve, for real duty.

Fenton's Spherical Safety-Valve.—This valve is designed to remedy the defects of the old class of "mushroom" safety-valves, which, not so obvious on locomotive-boilers, are sources of anxiety in marine or stationary boilers, by the valves adhering to their seats, or fixing themselves by the spindle or one or more of the joints. Fenton's "single valve," Fig. 57, is spherical; all the bearings are ball-and-socket, to promote freedom of action; and, to insure against corrosion and sticking, the ball is of gun-metal, and the seat of brass. If the ball wears, it may be turned into a new position. The same prin-

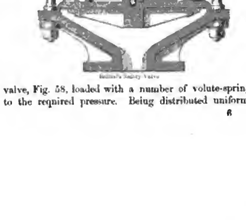


Fenton's Spherical Safety-Valve.

ciple is observed in Fenton's "double valve," with a double spring-balance, in which the design is to prevent the danger of overpressing the boiler. The two valves are placed under one lever, with a spring at each end, and they are each the fulcrum of the other; so that when the spring-balance is too lightly screwed down, the superior power of the other spring blows off the steam by one valve; and if too heavily screwed or loaded, the other spring, of relatively inferior power, gives way, and the other valve blows off. The presence of the back spring is thus a security against tampering with and fixing the valve; being covered, of course, lock-nutted, and padlocked.

The double valve is good in principle, having elasticity at both ends of the lever, partaking of the character of a direct-action valve; and, having a double exit, it permits the surplus steam to blow off faster than a single valve. It is said to work satisfactorily on stationary boilers. The single valve has been at work on locomotive-boilers for some years.

Baillie's Safety-Valve.—This is a large direct-action



Baillie's Safety-Valve.

valve, Fig. 58, loaded with a number of volute-springs, to the required pressure. Being distributed uniformly

* The Author did so experimentally, in 1850, diverting the current from the lower half of the tubes, and carrying it around and below the cylinders, which were suspended within the smoke-box; but without any apparent advantage, probably because the cylinders had previously derived benefit from the hot smoke, the smoke-box being capacious, and chiefly because the hottest of the smoke passed off through the upper tubes.

† Our authority is a pamphlet, *On the Economy of Fuel on Board Steam Vessels*, by A. H. Renton, 1851.

around the centre of the valve, the joint action of the volutes is central and parallel to the axis of the valve; the bearing is flat, and there is no spindle, consequently no risk of jamming. This valve was introduced in 1854, and embodies the doctrine of direct action for safety-valves, worked out to very wide limits. Mr. Baillie has described the results of comparative trials of an ordinary lever safety-valve and his direct-action valve, on the same boiler; from which it appears that the trials were made on a locomotive-boiler, having 890 square feet of heating surface. The engine was not worked, and the draft was created by a ½-inch jet in the chimney, led through a small tube from the boiler. The two safety-valves were equally weighted, to 64 lbs. per square inch, and compared with the actual pressure in the boiler, by means of a manometer; the small valve was 3·6 inches in diameter, weighted with the usual lever and spring-balance, and the large valve was 12 inches diameter, weighted with seven volute-springs, as in Fig. 58. The large and the small valves were then set fast alternately, and the blow-pipe started in the chimney; the surplus steam escaped through the free valve in two successive trials, and it was found that under the stimulus of the ½-inch blast, the pressure, with the small valve in action, rose in four minutes from 64 to 105 lbs. per square inch, through 41 lbs. per inch. The valve was in good order, and rose 1/12 inch from its seat; the experiment was interrupted at 105 lbs., as the pressure continued to rise. With the large valve in action, and the blast worked as before, the pressure rose, in four minutes, from 64 lbs. to 76 lbs., through 12 lbs. per square inch; the fire was kept up for half an hour longer, but the pressure remained stationary at 76 lbs., the valve having risen 1/24 inch, sufficiently high to let off all the steam that was generated.

The opening of the large valve, 1/24 inch, multiplied by the circumference, was 1·57 square inches area; add the area of the ½-inch blast-pipe, ·196 square inch, and the sum, 1·766 square inch, was the total area of escape. The opening of the small valve, 1/12 inch high, was only ·942 square inch; and the total opening, with the jet, was 1·138 square inch. Thus the total opening for escape with the small valve, was about two-thirds of the opening with the larger valve; and it is remarkable how small an amount of extra opening sufficed to set free the whole of the steam that was generated.

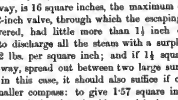
Subsequently, a trial was made, to ascertain how much water the boiler was evaporating during the trials. The firing was continued for a whole hour, the steam blowing off at 76 lbs. pressure through the large valve; and 80 cubic feet of water was evaporated in the hour.*

The results of these trials are corroborative of the Author's conclusions published in 1853, in *Railway Machinery*, page 228, maintaining that the more direct the action, or the less the leverage, the more efficient is the valve. It is not at all obvious, however, that a 12-inch direct-action valve is better than a valve of smaller size. On the contrary, it is most probable that a valve of, say, one-seventh the area, or 4½ inches diameter, fitted with a single volute-spring, would be at least equally efficient; as the circumference, which is a measure of the escape, is greater in proportion to the area, in the smaller than in the larger. The mere element of size of valve-way does not, in fact, bear directly on the question; for, whereas the area of a 4½-inch valve, or valve-way, is 16 square inches, the maximum opening of the 12-inch valve, through which the escaping steam was delivered, had little more than 1½ inch of area, sufficing to discharge all the steam with a surplus pressure of 12 lbs. per square inch; and if 1½ square inch of escape-way, spread out between two large surfaces, is sufficient in this case, it should also suffice if collected into a smaller compass: to give 1·57 square inch area of escape, a 4½-inch valve should open 1/9 inch; a 3½-inch valve, 1/7 inch; a 2½-inch valve, 1/5 inch; and a 1½ inch valve, 1/3 inch. Any of these diameters would do equally well, with a spring of suitable range and elasticity, for discharging steam rapidly; but it would be expedient to adopt a medium size, to insure against sticking in the seat. It is further to be observed, that, in small sizes, the smaller the valve, the greater is the practical difficulty of getting a spring that shall combine, in the requisite degrees, the required strength and elasticity; and possibly it was in contemplation of this difficulty, that Mr. Baillie adopted the large diameter of his safety-valve.

Under any circumstances, there should, in all cases, be at least one lever safety-valve, with a spring-balance within convenient reach of the engineman, who naturally tries this safety-valve at frequent intervals, to see that all is free.

Hawthorn's Annular Safety-Valve.—This ingenious valve, Fig. 59, differs from the ordinary disc-valve, in being

Fig. 59.



Hawthorn's Annular Safety Valve.

annular, not circular:—it is a ring, with two concentric edges for escape, not a disc, with one edge. Thus, with a given diameter, the extent of opening for escape, in the annular valve, may be nearly twice that of the disc-valve, whilst the surface under pressure, comprised in the annular space between the concentric edges, is necessarily less than that of the disc-valve; so that, upon the whole, with a given area and lift of valve, the amount of opening for the discharge of steam, is very much greater in the annular than in the disc-valve. This valve of course requires much less holding-down load than the other. The spindle of the valve is made hollow, and the pin bearing on the bottom of the socket thus formed, the valve is placed in a condition of equilibrium, and is free and frictionless in working. According to the results of careful comparative trials on the steam-boiler, it appears that, whereas, with the ordinary mitre-valve, with lever, the pressure rose 15 per cent. above that at which the valves were set with the annular valve, the surplus pressure did not exceed 3½ per cent.

* For the particulars and illustrations of Fenton's and Baillie's safety-valves, the Author is indebted to a paper *On the Application of Volute-springs to the Safety-valves of Locomotive-boilers*, by Joseph Baillie, read at the Institution of Civil Engineers, Session 1855–56.

The working of the annular valve, thus appears to be very superior to that of the large direct-action disc-valve, already described; should there be no practical difficulty in preventing it from sticking to its seat, the annular valve would no doubt be the most efficient safety-valve that has yet been produced.

CHAPTER XIV.

Feed-Water and Steam.

Feed-Water.—The quality of the water supplied to boilers has much influence on their efficiency. The water is seldom pure: it commonly holds in suspension mineral, vegetable, or animal matters, which are precipitated and deposited upon the heating surfaces of the boiler, impairing its evaporative power and economy, and destroying the material; or, if muddy in composition, causing the water to prime with the steam, to the prejudice of the working parts, and of the efficiency of the engine. Calcareous deposits are the most common in locomotive-boilers; in extreme cases, they have been observed to shorten the duration of fireboxes to a few months. In Ireland, the contrasts afforded by the use of hard water from calcareous soils, and of soft water from boggy soils, in neighbouring districts, are instructive; for, whereas the hard water has been known to terminate the useful existence of the firebox within three years, the boilers fed with bog-water have had their fireboxes good for eight or nine years. The injury inflicted upon those parts of the machinery which work amongst the steam raised from bad water, as the valves, pistons, and glands, is also considerable; for grit and mud are carried over in suspension, and accelerate the tear and wear of such parts. There is also a direct loss of heat by priming.

To remove such objections, the water should be purified by chemical or mechanical means, according to the nature of the impurities. For the removal of chemical impurities, there is no universal medicine; every variety of water must be analyzed and prescribed for individually, and this can be carried out at a small cost.

The practice of heating the feed-water by the waste steam is still very far from being general. Of its economical advantage there is no doubt whatever,—to the extent of 12 to 15 per cent. at least. A simple means of doing it is a desideratum.

Steam.—It appears from the investigations of Professor Rankine, of Glasgow, and others, that the relative volume of steam is less than has commonly been assigned to it by Pambour and others, following the laws of Gay Lussac and Mariotte; and as adopted in *Railway Machinery* and *Railway Locomotives.* Pambour's tables are, in fact, wrong; he treated ordinary steam as a permanent gas, though in fact it is saturated vapour. Regnault's experimental investigations on the relative volume of steam of various pressures, have not yet been published, so far as the Author is aware. Meantime, it is deducible from the doctrine of the mechanical equivalence of heat, that steam at the ordinary pressure now adopted in locomotive practice, 130 lbs. per square inch, above the atmosphere, though usually supposed to have a relative volume 210 times the volume of the water at 60° from which it is generated, is in fact only 190 times the volume of the initial water;—showing a reduction of 20 per cent. in fact upon what was formerly supposed. Of course, the discovery will not incur any extra expenditure of fuel, but it will so far explain the apparent priming of large proportions of water estimated by means of the ordinary tables of the properties of steam to pass over with the steam in many cases of ordinary practice.

To convert steam into a perfect gas, it must be heated above the temperature due to the pressure; at 130 lbs. above the atmosphere, it requires 50° additional temperature. It is established that the full measure of advantage by expansive-working is only to be had by the adoption of a process of superheating; and recent experience in ordinary engines would show something like an economy of 20 to 30 per cent. of steam, when the process is thoroughly applied. Something must be done in this way for locomotives, and it would be the most important step in economizing expenses, next to the substitution of coal for coke.

OF THE ENGINE.

CHAPTER I.

Details.

Pistons.—Pistons have been made in a variety of ways, and with various degrees of refinement, in order to work and wear freely, equally, and durably. Experience shows that they may be very much simplified and otherwise improved, without deteriorating from their effectiveness:—that, whereas pistons of the type heretofore prevalent, are composed of from twelve to twenty-four or thirty pieces,—any one of which is liable to become loose and derange the whole construction,—it is found that a piston may be made out of three or four pieces, to work fully as well as the older and more elaborate piston, to work longer, to require less frequent inspection, and lighter and less frequent repairs. There are several very good and simple pistons now at work, and they are chiefly of two classes:—those which are made to depend on the admission of steam within the packing rings for the needful pressure upon the surface of the cylinder to make a steam-tight piston, and those which are designed by the elasticity of the rings themselves to effect the same object. The distinction is perhaps only conventional, for it seems very probable that steam from the cylinder does find its way behind the ring under all ordinary circumstances. Ramsbottom's piston, Fig. 60, is the most curious development of the self-acting class of piston:—the body of the piston being a plain casting in one piece,

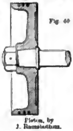
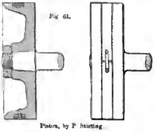


Fig. 60

Piston, by J. Ramsbottom.

and the packing consisting of two or more small rings of iron or steel, ½ inch or $\frac{5}{8}$ inch square, in one piece, cut at one place, and let into fitting grooves on the circumference of the piston. These rings work for months, until they are worn through, before requiring renewal. A very widely used class of piston, and one which gives general satisfaction, consists of a single casting, with a single cast-iron packing ring sprung into a groove turned on the rim, of which the piston, Fig. 61, adopted by Mr. P. Stirling, on the Glasgow and South-Western Railway, is an excellent example. The ring is 1½ inch by ½ inch thick, made steam-tight with a tongue and rivetted to the body of the piston, and let into slots in the ends of the ring, as shown in the appended plan. This piston is light and simple, and it appears to meet all the requirements of the situation.

Fig. 61.



Piston, by P. Stirling.

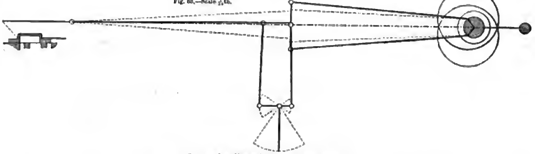
Of pistons which are constructed to depend for their steam-tightness on the pressure of steam admitted behind the ring, Mr. Wakefield's, of the Great Southern and Western Railway of Ireland, is a good example. Mr. Wilson, on the Oxford, Worcester, and Wolverhampton Railway, inserts a single ring, Fig. 62, with a small degree of slackness.

Fig. 62.

Piston, by Edward Wilson.

Valve-Gear.—The only novelties of importance, are those of Mr. Isaac Dodds of Rotherham,—a wedge-motion; and of Mr. Henry Dubs, now of Glasgow, applied to engines built at the Vulcan Foundry, Warrington, and illustrated in Plate XXXI.*, on the Vale of Neath tank-engines, and in Plate XXXIX.*, on the Dublin and Wicklow engines; and of Mr. Allan, of Perth, illustrated in its application to Allan's engine, Plate XL.* Mr. Dubs applies but one eccentric for each valve, and operates it for expansive-working and reversal by means of a system of inclined planes and wedges. This motion is found to work satisfactorily. Mr. Allan's motion,—a modification of the link-motion, is further illustrated by the diagram of its centre lines, Fig. 63. It

Fig. 63.—Scale $\frac{1}{24}$th.



Straight-Link Motion, by Alexander Allan, Perth.
Eccentrics 4½ inches throw, Rods 50½ inches. Link, 10 inches long. Lap of Valve 1 inch, Lead ¼ inch.

is called the "straight-link motion," the expansion-link being straight, and not curved as usual; the expansion-link and radius-link, the latter carrying the block or dies, are both suspended by levers on the same transverse shaft, but inversely, so that, for expansive-working or for reversal, the one is travelled upward and the other down-

TABLE No. XL.—OF THE DISTRIBUTION OF ALLAN'S STRAIGHT LINK-MOTION.

ARRANGED FOR THE ENGINES OF THE LONDON AND SOUTH-WESTERN RAILWAY.

Outside lap of Valve, 1 inch. Inside, Line and Line. Steam-ports 1¼ inch wide. Exhaust-port 2¾ inches wide. Eccentrics 4½ inches throw. Cylinders 16 × 22 inches.

Notch.	Lead.		Opening of the Port.		Point of Suppression.		Point of Release.		Period of Expansion.		Period of Compression.		
	Front Stroke.	Back Stroke.	Front Stroke.	Back Stroke.	Front Stroke.	Back Stroke.	Front Stroke.	Back Stroke.	Front Stroke.	Back Stroke.	Front Stroke.	Back Stroke.	
	inches.	inches.	inches.	inches.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	per cent.	
4	$\frac{1}{16}$	$\frac{1}{16}$ F	1	$1\frac{1}{16}$	75	74	92	91	17	17	8	9	Forward.
3	¼ B	¼ B	¾ B	¾	64	63	88	86	24	23	12	14	
2	¼	¼ B	$\frac{9}{16}$ B	½	51	51	83	80	32	29	17	20	
1	¼ F	¼	⅜ B	¼ B	29	30	72	68	43	38	28	32	
0	¼ F	¼	¼ F	¼	12	11	52	49	40	38	48	51	
0	¼ F	¼	¼ F	¼	14	10	52	48	38	38	48	52	Backward.
1	¼ F	¼	⅜ B	¼ B	30	27	71	67	41	40	29	33	
2	¼	¼	$\frac{9}{16}$ B	½ B	51	49	82	79	31	30	18	21	
3	¼ B	¼ B	$\frac{11}{16}$	¾	61	57	86	83	25	26	14	17	
4	$\frac{1}{16}$ F	¼ B	1 B	$1\frac{1}{16}$	75	72	92	90	17	18	8	10	

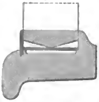
Note 1.—The suppression, release, expansion, and compression of steam are expressed in percentage of stroke of piston.
2.—The front stroke is described by the piston moving from the buffer-beam towards the firebox.
3.—The initials, F and B, in the columns of Lead, and Opening of the Port, express *full* and *bare*.

ward simultaneously:—they both move, and meet each other half-way, and the extreme vertical movement of each is only about half that which would be assigned to either, if the other were hung from a stationary centre, as in the ordinary link-motion. The accompanying table, No. XI., showing the distribution obtained by Allan's motion, according to the proportion in Fig. 63, shows that its action is equally good with ordinary links.

Equilibration of Engines.—Since the publication of the Author's discussions on this subject in *Railway Machinery*, in 1852, which was at that time imperfectly understood in this country, it has commanded great attention, and locomotive-stock generally is in course of being correctly balanced. The benefits of equilibration show themselves in many ways,—chiefly in economy of fuel and of repairs. The "Canute" passenger-engine, on the London and South-Western Railway, had a balance-weight of 85 lbs. applied within the rim of each driving wheel; the Author was allowed to apply a weight of 186 lbs. in each wheel, to balance the reciprocating parts, and the engine ran so much more steadily and freely with the new balance weights, as to take the engineman by surprise:—on the first day after the alteration, the engine considerably overshot the stopping stations. The consumption of fuel fell 3 lbs. per mile. The other passenger-engines were equilibrated with similarly good results; and on applying proper balance-weights to the outside-cylinder goods-engines, the average result of four of these engines, showed that, before equilibration, the consumption of fuel was 27 lbs. per mile, with an average train of twenty-eight waggons; and after equilibration, 23 lbs. per mile, with twenty-seven waggons. Generally, it is found that a reduction of 10 per cent. clear is effected by the application of balance weights.*

Elastic Wheels.—In the "horse-foot" wheel-tyre of Mr. W. B. Adams, Fig. 64, the tyre is formed with a deep internal rib abutting against the face of the wheel, and a continuous hoop-spring of tempered steel overlaying a continuous hollow in the internal periphery of the tyre, on which the wheel rests. The wheel is forced on by a gentle pressure without heating the tyre, and is retained by a flat ring sprung into a groove at the back, thus preventing the wheel from getting out, and no other fastening is needed.

Fig. 64.



"Horse-foot" Wheel-tyre, by W. B. Adams.

The comparative simplicity of this wheel is apparent; and, thus completed, it is analogous to the foot of a horse, standing on a continuous spring. This system has been successfully practised on the North London Railway, where a set of four solid wrought-iron disc-wheels, 3½ feet in diameter, was fitted with Staffordshire tyres so constructed, and placed under a carriage weighing 5½ tons. At the same time, a set of wrought-iron spoke-wheels, of the same diameter, were furnished with Lowmoor tyres, shrunk and rivetted on in the usual manner, and were placed under a similar carriage. The annexed figures (Figs. 65 and 66), show in section the respective wear of the tyres after running 45,000 miles in

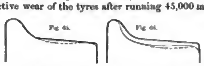


Fig. 65. Fig. 66.

Comparative Sections of Iron Tyres.—Fig. 65, Horsefoot Tyre—Fig. 66, Ordinary Tyre.

the same trains; and they indicate that the Staffordshire tyres on springs, had worn on the tread one-half less than the Lowmoor ordinary tyres. Wheels on this system have worked satisfactorily, also, on the Eastern Counties Railway, for upwards of two years; under carriages, break-vans, and coupled engines. The saving of working expenses, in the stock and the road, by a system of elastic wheels, versus rigid wheels, would be of unquestionable importance.

* See a paper by the Author, *On the Improvement of Railway Locomotive Stock, and the Reduction of the Working Expenses*, read at the Institution of Civil Engineers, November 11, 1856, vol. xvi., Minutes of Proceedings.

CHAPTER II.

Working Dimensions and Arrangement of Engines.

The working pressure of the most recently designed locomotives varies from 120 lbs. to 140 lbs. per square inch. Decided advantages are found to attend the employment of such high pressures, in economy and in the development of power. In narrow-gauge engines, with inside cylinders, the greatest available diameter of cylinders, consistent with the use of simple and direct connections about the framing and the gearing, is 16½ inches or 17 inches; and the greatest length of stroke consistent with the most desirable disposition of the machinery and proportion of working parts, is 24 inches. For regular main-line traffic, the smallest diameter of wheels now adopted is about 5 feet for goods-engines, and the greatest diameter is 7 feet for passenger-engines. For high-speed goods-engines, 6-feet wheels have recently been employed. The inducement to the use of large wheels, originates partly in an impression that wheels of smaller diameter do not bite so efficiently as those of larger size; but whether or not the greater leverage of the cylinder upon the smaller wheels, and its greater power of slipping them, has anything to do with it, general experience, at all events, does not corroborate the impression. Banking engines, and others with very low wheels, are found to work well up to the maximum adhesive power of driving wheels generally.

In average recent practice, the most powerful narrow-gauge goods-engines are made with 16-inch cylinders, 24 ins. stroke, and 5-feet wheels, all coupled, with 140 lbs. steam. The most powerful passenger-engines have the same dimensions of cylinders, and 7-feet driving wheels; but cylinders 15 or 16 inches by 20 or 22 inches, and 6-feet wheels, prevail in passenger-engines. It is said, however, that the 7-feet wheel gives more economical results than the 6-feet. For outside cylinders, which have facilities for enlargement, it is not found in practice that there is any benefit from extra capacity of cylinder, in goods-engines. The 16-inch cylinder, the 24 inches stroke, and the 5-feet wheel for main-line goods-engines, appear as the result of experience, to be the most generally satisfactory and permanent set of dimensions, taken in connection with an elevated pressure in the boiler. Broad-gauge goods-engines have subsided into the same set of dimen-

sions, with 120 lbs. steam. In broad-gauge passenger-engines, 17-inch cylinders, 24 inches stroke, and 6½-feet or 7-feet wheels are employed; and it would appear that the working dimensions for main-line goods-engines, are based practically on circumstances other than the accident of gauge.

Nevertheless, of late, 6-feet wheels and 18-inch cylinders have been tried for goods-engines, and are said to have given results sufficiently satisfactory to warrant further trials in the same direction.

For high-speed heavy passenger-trains, four-coupled wheels of large diameter, are now frequently preferred to single wheels. In all his new eight-wheel passenger-engines, Mr. Gooch couples the hind wheels.

On the contrary, four-coupled six-wheel engines are, in certain circumstances, found preferable to six-coupled engines, on account of their greater simplicity, their greater freedom of working, and greater efficiency in proportion to the whole driving weight, and their superior durability and economy in repairs. The inequality of the loads on three-coupled axles, and the unequal wear of the tyres, reduce the wheels to unequal diameters; and the uniformity of revolutions enforced by the mediums of the coupling rods, induces violent strains upon all the parts of the machinery directly concerned, increases the working friction, even if the wheels do wear equally,—and reduces the effective power of the engine. There is no doubt that, when an engine is new, or in first-rate order, the effective tractive force of six-coupled wheels under the engine is something more than that of four-coupled wheels; but it wears as it works, and loses the exact fitting and parallelism of parts, and the internal friction, with the absorption of power within itself, increases in the same ratio. But the wear may be repaired, of course, and the engine restored to good order; or, with constant attention, it may be maintained in a high state of efficiency; and there is no doubt, notwithstanding the greater cost of maintenance, that where the goods traffic is heavy,—great loads and high speeds,—and where the line is free from quick curves, the six-coupled engine may be advantageously employed in preference to the four-coupled. The curvature of a railway is an essential element in the question of the expediency of four-coupled *versus* six-coupled wheels:—the resistance on a curve is much greater than on a straight line, and with six wheels coupled, it is decidedly greater than with only four wheels coupled. To any one who has observed the grinding of a six-coupled engine on a siding, and the comparative freedom of four-coupled wheels, this must be obvious, and it is demonstrated as the general practice of lines of quick curvature, that six-coupled engines do not take heavier trains than four-coupled. Accordingly, the experience on the more recently constructed lines,—such as have steep gradients but quick curves,—points decisively in the direction of four-coupled engines as the most serviceable for goods traffic. On the contrary, the experience of the old lines,—for the most part easy in gradients, and in curves,—adheres firmly to the six-coupled goods-engine. The metropolitan lines, with but two exceptions,—the London and South-Western and the Eastern Counties,—are stocked with six-coupled goods-engines; and they are lines generally free from quick curves.

It may be concluded generally, that the adoption of six-coupled or four-coupled engines for goods traffic is dependent upon the character of the traffic, but principally upon the engineering character of the railway; and is not to be decided by abstract arguments.

Boilers.—The author has uniformly adhered to the practice of small fireboxes as opposed to large boxes:—that is to say, to fireboxes large enough for the proper combustion of the needful quantity of fuel, but not larger than necessary; in order, first, to limit the spread of the fuel, and to intensify the combustion, so as to excite a high temperature in the firebox, and a proportionally rapid and thorough absorption of heat; secondly, to approximate the absorbing surfaces to the source of the heat, and fully realize the benefit of the radiant heat, and so further accelerating the absorption of heat. For, it must be observed, that the problem of the entire absorption of heat into the boiler, and the reduction of the waste heat passed into the chimney, is dependent on special proportions, and not merely on the abstract quantity of heating surface. It does not necessarily follow, for example, that, because one boiler contains 100 square feet of firebox heating surface, and 1200 square feet of tube-surface, it is more powerful or more efficient than another boiler with 75 square feet in the firebox, and 900 feet in the tubes; that depends very much on the details. The use of mid-feathers or partitions is, no doubt, conducive to this end, but the efficiency of such elements is dependent very much on the way they are placed. With a transverse partition, the front compartment consumes a much larger proportion of fuel than the back one,—as much as two or three times,—supposing an ashpan open to both; and the concentration of duty within one compartment, having a superior command of draft, is equivalent in effect to the use of a smaller firebox. With a longitudinal partition, the draft is the same in both compartments, but its absorbing surfaces are better situated for participating in the benefits of radiated heat, and, being carried to the roof of the firebox, the extent of surface is greater than that of the transverse partition. General experience shows that partitions judiciously inserted into large fireboxes, increase the evaporative efficiency of the boilers, partly by reducing the grate, and partly by increasing the absorbing surface of the firebox; and, conversely, that their removal from large boxes reduces the efficiency of the boiler, and incurs an extra consumption of fuel. On the contrary, partitions are generally troublesome and expensive in maintenance, unless fully and quickly rounded into the walls of the firebox, as practised by Mr. Cudworth. Upon the whole, a comparatively small, open firebox, is better than a large box, whether made plain, or partitioned.

Tubes.—In recent practice, generally, tubes are packed closely into the barrels:—the more the better, it appears to be considered; from 200 to 250 tubes in a 4-feet barrel, with ⅜ or ¼ inch of clearance. This is a great practical blunder;—140 to 160 tubes 1¾ inch or 2 inches diameter outside, properly spaced apart, and 10 to 12 feet in length, are absolutely better for steaming and economy of fuel, than much larger numbers. For detailed evidence on the important questions of boiler power and efficiency, the Author refers to *Railway Machinery* and *Railway Locomotives.*

DIVISION II.—AMERICAN LOCOMOTIVES.

THE following is not intended as a treatise on the locomotive, but as forming such a section of *Railway Locomotives* as shall illustrate the chief points of difference between American and English practice. The discussion of the general principles, common to all engines, has been so thoroughly performed by Mr. Clark that, in all cases where such principles arise, readers are referred to his portion of the work. This, it is believed, makes the whole plan of the present volume more symmetrical, and correspondingly more useful.

ZERAH COLBURN.

CHAPTER I.

HISTORICAL PROGRESS OF THE LOCOMOTIVE.

No history of American locomotives would be ranked as orthodox, unless it commenced with the exploits of Oliver Evans, of Philadelphia, in 1804. Mr. Evans was an ingenious, and, as time has proved, a far-seeing man. He experimented with steam as a motive power in 1772. In 1787, he patented a "steam-waggon," and applied to the legislature of Pennsylvania for permission to run it within that state. The committee, to whom Evans' application was referred, heard him patiently, but, concluding that he was insane, refused all encouragement. Seventeen years afterwards, in 1804, having built a steam dredging-machine in his establishment, a mile and a half from the water, Evans fitted rude wheels and axles under the "scow," and geared them to the internal propelling apparatus. By this arrangement, he rendered the whole self-moving, and he actually propelled the amphibious affair along a crowded street, to and into the water. The launching gear being removed, the machine was put to its legitimate work, and this was the last attempt of Evans at steam-locomotion.

For what he did in explanation and advocacy of steam-locomotives, Oliver Evans will be always remembered as a deserving pioneer in their development. But his single practical demonstration proved no more than was already known of Murdoch's steam-carriage, run twenty years before in England. Nor is it probable that Evans' feat had the slightest influence in the subsequent adoption of steam on railroads. For, notwithstanding the fact that steam was successfully used in England in 1814 for moving coal trains, and notwithstanding that two railroads —the Quincy and the Mauch Chunk—were completed in the United States in 1827, and that other railroads were soon afterwards built, the first steam-locomotive ever run upon a railroad in the United States was the "Lion," imported by the Delaware and Hudson Canal Company, as late as 1829, and run in August of that year. The success of railway locomotives in England had become well known in the United States, and by the beginning of 1830 the triumph of Stephenson's "Rocket" was a theme of ordinary conversation among the railway projectors of the day.

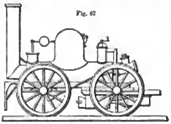
The "Lion," already referred to, was one of two locomotives built at Stourbridge, England, to the order of Horatio Allen, Esq., now of New York. They had each two straight flues in the boiler, and were of the form used prior to the "Rocket." They did not prove successful.

In 1829, a steam-carriage with three wheels and two six-inch cylinders was built by William T. James, of New York, and was run there on several occasions. Mr. James' connection with railway engines will be mentioned presently; but it may be here remarked that his steam-carriage had four eccentrics, and that the valve of one cylinder had one half-inch lap on each end, and exhausted the steam into the other cylinder. The waste steam was discharged through a contracted pipe into the chimney. The use of two eccentrics for each valve was patented in the United States, January 17, 1833, by Messrs. Norris & Long.

Early in 1830, an engine was built at the West Point Foundry, New York, under the directions of Mr. Adam Hall, for the South Carolina Railroad. No particulars of its performance are on record, excepting that it blew up shortly after being put in use. In the same year a second engine was built at the same place, for the same road.

In the beginning of 1831, an engine called the "De Witt Clinton" was built at the West Point Foundry, and in July of that year it was placed on the Mohawk and Hudson (now part of the New York Central) Railroad. This machine had four wheels, all of 4½ feet diameter, and connected by coupling-rods. The cylinders were 5½ inches in diameter, the stroke of piston 16 inches, and the connection was made to the double-cranked axle of the front pair of driving wheels. The boiler was multitubular; the tubes, about thirty in number, were of copper, a quarter inch thick, 5 feet long, and 4 inches in external diameter. The annexed cut, copied from a sketch in the *Wadsworth Athenæum* at Hartford, Conn., represents this engine. The weight of the engine was four tons. It carried but three of the small passenger cars of that time over the road; but alone, it was run at a speed of forty miles an hour.

Fig. 62



The "De Witt Clinton," 1831.

On the 4th of January, 1831, the president of the Baltimore and Ohio Railroad Company offered 4000 dollars

for a locomotive of 3½ tons weight, which should draw 15 tons at 15 miles an hour on a level. The engine was to burn anthracite coal; it was to have four wheels, coupled together, four feet between centres in order to pass along curves of 400 feet radius. The steam pressure was not to exceed 100 pounds to the square inch. Phineas Davis, of York, Pennsylvania, produced an engine, in June, 1831, which fulfilled all these conditions. It had an upright boiler, and tubes, and upright cylinders; a beam being used to transmit the power to the crank, which was on a shaft connected by toothed wheels to the axle. Similar engines, of 12½ tons weight, are yet at work.

In 1832, William T. James completed at his establishment, in the city of New York, a locomotive intended for the Baltimore and Ohio Railroad. The boiler was upright, the cylinders 8 inches bore, and stroke of piston 12 inches. There were four wheels, 3 feet in diameter; one pair only being used as driving wheels. This engine had lap-valves and a species of link-motion, with double eccentrics. The link was hit upon and employed as a reversing gear. In setting the eccentrics, it was found that the suppression of the steam (already ascertained as due to the lap-valve) could be varied by the new reversing apparatus, and without interfering with the effective admission or exhaust. A graduated stop was then immediately arranged, and the engine was afterwards worked successively at different rates of expansion. The valve-chests were on the top of the cylinders, the steam-ports 5 by ⅞ inches, exhaust-ports 5 by 1½ inches; lap of valve ⅛ inch on each end. The engine burned anthracite coal, and steamed freely. Before this engine was sent to Baltimore, it was run for some time on the Harlem Railroad, where it worked satisfactorily. In 1833, it was forwarded to its destination, but, soon after having been placed in regular service, it exploded. Mr. James also applied to his engine a "spark-arrester," substantially the same as is now in use on all American wood-burning locomotives.

Matthias W. Baldwin, Esq., of Philadelphia, still at the head of one of the most successful firms in the locomotive manufacture, was the first to introduce into the United States the general features of the improved class of English engines, as developed upon the Liverpool and Manchester line, immediately subsequent to the trial of the "Rocket." Mr. Baldwin had built, in 1831, a working model of a locomotive for Peale's Museum, in Philadelphia. This was placed on a circular track, and drew a car containing five or six persons at a time. Thousands flocked to see it, and the Philadelphia and Germantown Railroad Company gave the builder an order for an engine in 1832. This was completed in January, 1833. It was called the "Old Ironsides," and weighed 5 tons. In the summer of 1833, it was run upon the Germantown Road at the rate of 62 miles an hour,—several persons on the engine having carefully timed it,—among whom was Dr. Patterson of the University of Virginia. The engine ran 2½ miles, in which were four very short curves, in 3¾ minutes, or at a speed of 40 miles an hour. The whole performance was carefully chronicled in the journals of the day. The valve-motion of this engine was obtained by a single fixed eccentric for each cylinder, the extremity of the eccentric rod being double-forked, so as to engage with either the upper or lower arm of a rocking-shaft, as in Carmichael's arrangement, at that time in use in England. In the general proportions of the engine there was an approximation to those already adopted abroad. Mr. Baldwin was the first to introduce the fastening of the cylinders to the outside of the smoke-box, and, what was much more, he patented and first used the metallic ground joint for cylinder and steam-chest covers and steam-pipes. In 1833 and 1834, Mr. Baldwin built five engines; in 1835, fourteen; and in 1836, forty. Nearly one thousand had been built at his establishment, in 1858.

In 1830, Col. Stephen H. Long, of the U. S. army, patented certain improvements in steam-locomotives. In March, 1831, a charter was obtained for the "American Steam-Carriage Company," and their first engine, embodying Long's patents, was built at the Phœnix Foundry, Kensington, and placed on the Newcastle and Frenchtown Railroad, July 4, 1832. This engine had not sufficient heating surface, and consequently could not keep itself in steam.

In the meantime, notwithstanding the successful manner in which Stephenson's engine was working on the Mohawk and Hudson, and Bury's engine on the Petersburg Road—both having been imported in 1831—increased efforts were directed to the adaptation of the locomotive to the curves of the new lines, and in doing this the whole plan of the engine was sometimes changed. In the beginning of 1832, Horatio Allen, of New York, had placed upon the South Carolina Railroad, a locomotive in which the boiler of a single engine might be said to be placed on the independent running gear or carriages of two ordinary locomotives. The whole machine had eight wheels, two pairs being driving wheels and the others small carrying wheels. Each pair of driving wheels, together with a pair of carrying wheels, was placed under a swivelling frame, which carried the corresponding end of the boiler on a pivot and side rollers. The two pairs of driving wheels were under the central part of the engine, the small wheels being at the ends. Each driving axle had one cylinder with its valve gear. By the end of 1833, four of these machines had been placed on the same railway, but their use was shortly afterwards abandoned.

In August, 1832, an engine called the "Experiment" was placed upon the Mohawk and Hudson Railroad, having been the first ever made in America, with four swivelling carrying wheels, substantially as now used under all American passenger-engines. This engine was built also by Adam Hall, of the West Point Foundry. It had 9½-inch cylinders, 16-inch stroke, one pair of 5-feet driving wheels, and a furnace grate 5 feet long, designed to burn anthracite coal. The whole weight was 15,000 lbs.

The "Robert Fulton," the first English passenger-engine ever run in the United States, was built by R. Stephenson & Co. for the Mohawk and Hudson Co., and the drawings which came with it were dated July 4, 1831, the machine being set up and running within two months from that date. It had four driving wheels, each 4 feet in diameter, and coupled by rods working upon cranks outside of the wheels and frame. It had 10-inch cylinders and 14-inch stroke, the cylinders being inside of the smoke-box. The weight of the engine was 12,842 lbs. It was frequently run with its full train of passengers 25 miles an hour. In the winter of 1832–3, this engine was altered, and christened the "John Bull." It was fitted with a truck, similar to the "Experiment," the change having been

made under the direction of the engineer of the company, Mr. John B. Jervis.

A truck frame, arranged to swivel on two side pivots—the motion resembling that of a parallel rule—was applied in September, 1832, to an English engine, the "Herald," at that time just placed upon the Baltimore and Susquehanna Railroad. The use of this arrangement commenced October 6, 1832.

In 1845, the "John Bull," already mentioned, was rebuilt by Walter M'Queen, and called the "Rochester." The first application of air-vessels to both the forcing and suction sides of the locomotive-pump is believed to have been made at this time, Mr. M'Queen having taken portions of the 4-inch copper tubes of the "De Witt Clinton" to form these vessels. The arrangement thus introduced is now universal in American engines.

In June, 1833, the "Black Hawk," built by Long & Norris, who were the survivors of the "American Steam-Carriage Company," was run upon the Philadelphia and Columbia and the Philadelphia and Germantown Railroads. Messrs. Long & Norris had already patented the use of four eccentrics, although, as has been shown, these were first used by James. In 1834, the same firm built three locomotives designed for burning anthracite coal. These were placed on the Boston and Providence Railroad, but anthracite being abandoned for wood, the engines were laid up in ordinary.

As examples of the performances of engines during the few years subsequent to 1830, two instances may be cited. One of Phineas Davis' small engines, with upright boiler, cog-wheels, and beam connection, took an excursion train out of Baltimore, August 16, 1832, of which the particulars were as follows:—There were six passenger-coaches containing 90 passengers; the train was carried 41 miles out and the same distance home,—part of the way (for 4 miles) up grades, varying between 32 and 57 feet per mile, the speed on these grades being 13 miles an hour, and for the whole trip each way, including stops, a fraction over 13 miles an hour.

The English engine (Bury's) called the "Liverpool," on the Petersburg Railway, weighed 11,200 lbs., had 9-inch cylinders, 18 inches stroke, four wheels, worked with 50 lbs. of steam, the lock-valve blowing off at 60 lbs. In the month of November, 1833, this engine drew fifteen waggons and one passenger-coach at 15 miles an hour on a level, and went up a grade of 30 feet per mile at from 8 to 10 miles an hour,—stopping and starting on the grade. The weight of goods and passengers carried was 83,620 lbs., of the cars, coach, and engine, 67,500 lbs.; total, 151,120 lbs., or nearly 62½ tons of 2240 lbs.; or 75½ tons of 2000 lbs.

In 1834, William Norris bought the interest of his partner, Col. Long, and commenced what afterwards became one of the largest locomotive building establishments in the world,—in which 150 engines have been built in one year. In conjunction with Long, Norris had patented —December 30, 1833—the use of the separate expansion valve, working directly on the back of the main-valve, a feature long afterwards preserved in the Norris engines. In July, 1836, Norris had completed an engine, the "George Washington," embodying considerable advances in proportion, arrangement, and construction upon previous plans. This engine weighed 14,390 lbs., and on July 10, 1836, it drew an additional load of 19,200 lbs. up an incline of 2800 feet in length, and rising at the rate of 369 feet per mile, or 1 in 14. The rate of speed up this incline was 15¼ miles per hour, the run of 2800 feet being accomplished in 2 minutes 1 second. The combined gravity and friction of the whole weight of 33,590 lbs. on the incline of 1 in 14 would be about 2600 lbs., which amount of adhesion was nearly or quite one-third of the entire weight on the driving wheels. It is not now certain, however, how far the weight of the tender was made to rest upon the drivers; especially as in the published account of the exploit, the pressure of steam was reported as being but 60 lbs. per square inch. This pressure, exerted upon the piston of the engine in question, and through the leverage of its crank and driving wheels, would be as incapable of raising 33,590 lbs. up an incline of 1 in 14 as would 2 lbs. be incapable of raising 3 on a scale-beam of equal length from the fulcrum. Since that time there has been additional proof, however, that the adhesion of driving wheels under some circumstances is occasionally greater than even one-third of the weight upon them. But in 1836, such a feat as was achieved by the "George Washington," took the engineering world by storm, and was hardly credited. The directors of the Birmingham and Gloucester Railway, of England, became so convinced of the efficiency of the Norris engine as to order several for working the Lickey Incline, where they performed successfully until further improvement had rendered them antiquated.

The Norris engine, as it was at the commencement of 1837, may be described as follows:—The boiler was of the dome pattern, known in England as Bury's boiler, and used by him in 1830; the framing was of flat wrought-iron bars; the driving axle had two inside bearings, as in Bury's engines of some years' earlier date. The cylinders were placed outside of and fastened to the smoke-box, as well as to the frame. The engine was supported on one pair of driving wheels—placed just in front of the firebox—and by a swivelling, four-wheeled truck, placed under the smoke-box. The centre of the truck being so much in advance of that of the leading wheels in the English engines, there was a considerably greater proportion of the weight placed upon the driving wheels, while it was not unusual also to adjust the draw-bar so as to throw a portion of the weight of the tender upon the hind end of the engine when it was drawing its load. The engine had an advantage over other plans in the use of four fixed eccentrics, although these could of course add nothing to the dynamical effect. The valve-motion was, nevertheless, efficient, as the performances of the engines fully attested.

The Baldwin engine of the same period had a similar boiler, and a similar position and fastening of the cylinders. The driving wheels were placed behind the firebox, the usual truck being placed under the smoke-box. These engines ran steadily owing to their extended wheel-base; although they did not have the weight on drivers, and the consequent adhesive power of the Norris engines. The framing was of wood, covered with iron plates, and was placed outside of the wheels, the driving axles having two bearings only. The cylinders, although outside of the smoke-box, were placed so as to give a connection inside of the driving wheels. The crank was formed in the driving axle, but instead of forming a complete double or

bell crank, the wrist was extended through and fastened in a suitable nave or hub on the driving wheel,—the journal for the bearing being a simple straight stud inserted in the central nave of the wheel.

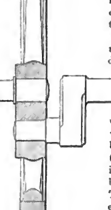


Fig. 64.

Section of Driving Wheel, showing Baldwin's Half-crank, 1837.

The guide-bar of the cross-head was a single hexagonal cast-iron bar, bored out to form the barrel of the pump.

This, requiring a long piston-rod, served to fill up the great distance between the cylinders and driving wheels, requiring a connecting rod of no more than 7 feet length. The valve gear, already described, was placed beneath the foot-board, the eccentric rods extending backwards to the rocking shaft, and the valve rods being of about 12 feet length. The pumps of these engines had each no fewer than five valves, three between the pump and boiler, and two between the pump and its supply pipe.

The "Locks and Canals Company," at Lowell, Massachusetts, had manufactured locomotives after Stephenson's models as early as 1834, and made few or no changes up to 1840.

The Norris and Baldwin engines had both their peculiar advantages and defects. The first, having a great proportion of weight on the driving wheels, much of it overhung, was powerful but unsteady and hard on the rails. The last, having its drivers behind, was steady, but had insufficient adhesion. Two pairs of driving wheels, in addition to the truck, were accordingly combined in the same engine by Eastwick & Harrison, of Philadelphia, and the equalizing lever introduced between the springs. The new engine, the "Gowan & Marx," was placed on the Reading Railroad, in January, 1840. Norris at once adopted the coupled drivers with equalizing spring-levers, and with the separate expansion valve and other features already embodied in his plans; his engine of 1840–46 may be taken as the standard type of American locomotive, to which other builders gradually approximated.

In 1840, Hinkley & Drury, of Boston, brought out an outside connected engine, with the cylinders entirely detached from the smoke-box and boiler, and supported only in a double frame, one bar serving to carry the pedestals or axle-guards of the inside bearings of the wheels, the other being placed outside simply to carry the cylinder, rocking-shaft, and pump, and to serve as a guard for the engine. This class of engine was built for several years, and the establishment, since grown into the "Boston Locomotive Works," has become the largest of its kind in New England.

From 1842 forward, the Philadelphia builders built six and eight coupled wheel engines.

In 1842, Ross Winans, of Baltimore, produced some rare specimens of locomotive engineering, designed for the freight traffic of the Western Railroad of Massachusetts. The cylinders were outside and level, with a long stroke of piston, which connected to a crank on a shaft geared by toothed wheels to another intermediate shaft, which in its turn, by cranks, connected to two pairs of driving wheels under each end of the engine, or eight wheels in all. The boiler was upright, about 5 feet in diameter, and designed to burn anthracite coal. These engines were known as "crabs," and were but for a short time in use.

In 1844, or thereabout, Mr. Winans brought out his present plan of burden-engine, which is, as a whole, the most peculiar engine in use in the United States. The wheels, all coupled, are but 43 inches in diameter, cast with chilled rims and clustered within a distance between extreme centres of but 11 feet 3 inches. The cylinders are level, the connection outside of the wheels. The frame extends backwards only to the firebox; the firebox itself, which is 7½ feet long, extends backward unsupported save by its fastening to the barrel of the boiler. The foot-plate for the firemen is on the tender,—the engineman rides on the top of the boiler, just behind the chimney. The valve-motion is a single lap valve, worked at pleasure either by eccentric at full stroke or by an abrupt cam-motion, adjusted to suppress the steam at half stroke. In every detail of construction the engine is alike peculiar, and in the strongest possible contrast with the proportions, arrangement, and workmanship of the standard American engine.

In 1846, Septimus Norris designed the ten-wheel engine, since considerably used; and in January, 1847, the first one was placed on the Reading Railroad.

In 1849, Rogers, Ketchum, & Grosvenor, who had commenced building locomotives as early as 1837, took a decided lead in the general proportions and arrangement of the locomotive, and the style established by them in 1850 became the most popular, and it was the most imitated of any in the country. The senior member of the firm, Thomas Rogers, may be fairly said to have done more for the modern American locomotive than any of his cotemporaries. In America the standard wood-burning engine of to-day stands precisely where he had brought it in 1852, and where he left it at his death in 1856. His influence thus strongly exercised, was not that of original invention, but of sound judgment,—a practical appreciation of what was best among all the diverse details of construction which he had found in the current practice, or which arose in his own efforts for improvement.

Mr. Rogers was the first in America to adopt and to establish, by adoption on the large scale of his own business, the present proportion of boiler for a given cylinder. He enlarged the grate area and heating surface liberally. He was the first to establish the 6-feet wheel in general use for express passenger-engines. He was the first to adopt the present form of boiler, the elevated crown of firebox, the rounded corners and double domes. He established the link-motion as a standard element, making it in its adjustments superior to any other valve-motion, and in workmanship one of the best points in the American engine. He adhered to the outside connection, and placed the cylinders horizontally in all his engines; he improved on the previous cylinder-fastening, making it both lighter and stronger. He was the first in America to insist upon and to practise the counter-balancing of the entire reciprocating parts; the first to thoroughly protect the

cylinders and valve chests from radiation. The spread-truck, with centre-bearing, was established, in its most approved form, in the Rogers engine. The expansion-brace, now used in all American engines for fastening the boiler, was brought out by Rogers. To recapitulate all the improved points of the current practice of to-day, which had their first development in the Rogers engines, would be a lengthy task. The general style initiated by him, including both proportion and workmanship, and which by general adoption on the part of other builders has become the standard engine of to-day, has proved itself in all parts of the country as the most efficient, economical, convenient, and durable.

CHAPTER II.

Historical Progress of the Locomotive—(*Continued.*)

It has been seen that while, up to 1850, there had been adopted many dissimilar patterns, there has been going on, since that period, a steady assimilation of style. At the present time there is one well recognized standard of locomotive, not only for a single class of traffic, but indeed for nearly all classes. This is the conventional eight-wheeled engine, with four drivers and a truck frame. And in most of its leading details, there is an almost exact agreement in the practice of the different builders. Thus, the outside connection is universally adopted for engines for the narrow gauges (4 feet 8½ inches, 4 feet 10 inches, and 5 feet). The cylinders are placed nearly or quite level,—the truck wheels being spread to from 4 feet 10 inches to 5 feet 6 inches between centres, to give the required room, as well as to secure steadiness in running. The framing is solid, where it was formerly rivetted together,—the bars lying on their flat sides, and the axle-guards or pedestals being welded on. The framing is always single, and inside the wheels. The springs of the driving wheels are always connected by equalizing levers, excepting in six-wheel combined engines, where one pair of springs are sometimes independent. The boiler has very generally two domes, the steam being drawn equally from each. The shifting link-motion is almost entirely used,—the valves being on the upper sides of the cylinders, and worked through the intervention of a rocker-shaft. The pumps are, in nearly all cases, "full-stroke," being worked directly from the cross-heads. Air-chambers and suction-chambers are always provided to secure a steadier flow of water and to ease the strain on the pumps. The cross-head and guide-bars are almost universally of one pattern, which will be shown among the illustrations of details. The regulator or throttle is almost always in the smoke-box. There are always two blast-pipes—excepting for coal burning engines—one for each cylinder, and the sizes, position, and fitting up of these pipes are quite peculiar as compared with English engines.

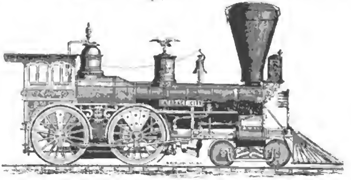
There are also the appendages which belong exclusively to American engines,—the house or cab, the "cow-catcher," the bell, the spark-arrester, &c.

The form and finish of details has assimilated to an equal degree. The boiler has generally received the high crown of outer firebox, as shown in the illustration, Fig 69. The cab, domes, "running-board," and other matters of external finish, are very much the same on most American engines. The driving wheels, connecting rods, boxes, cylinder-covering, &c., generally agree in form.

In size, while the boiler and cylinders are varied to suit the work, the wheels are less variable in diameter. Five feet is a common size of driving wheel for all classes of work, although 5½ and 6 feet are used to some extent for passengers, while perhaps a few engines, in the whole country, have 6½, 7, or 8 feet drivers, the latter size being for a single pair only. Heavy burden-engines, with six and eight coupled wheels, have drivers of from 43 to 56 inches diameter; two railways, the Baltimore and Ohio, and the Reading, have about 300 engines with wheels of but 43 inches.

On American roads of ordinary gradients and traffic, the principal difference between the passenger and the goods engines is a difference of 6 inches in the sizes of the driving

Fig. 69



Standard American Locomotive.—Danforth, Cooke & Co.

wheels, and an excess of from ⅛ to ¼ inch of inside lap in the valves of the goods-engine.

The experience, which has determined the standard plan of American engines, may be stated as follows:—As compared with English railways, the loads moved are heavy and the permanent way is weak; so, too, the gradients are long and steep, and the curves sharp. Hence, the greatest power must be exerted with the least injury to the track. Thus, instead of a single pair of driving wheels, bearing one-half the weight of the engine, two pairs coupled employ two-thirds of the whole weight, with 33⅓ per cent. less weight on a single point of bearing on the rail. Thus, a 24-ton American engine has, say 16 tons adhesive weight, with but 4 tons on any one wheel.

The office of the truck is apparent, in turning curves of short radii—often of 600 feet, while 955 feet is a very ordinary radius. The truck also, by its four wheels, distributes the weight of the forward end of the engine, and as its support is at or forward of the centre of the smoke-box, it throws more of the weight of the engine upon the drivers than would a pair of leading wheels placed behind the smoke box. To reduce the friction of swivelling, and

to take the weight equally on each truck-wheel, the truck-frame generally carries its load on its centre.

To secure the full power of the engine, when required, the valves have moderately short lap,—seldom over $\frac{3}{4}$ inch at each end, and generally but $\frac{5}{8}$-inch, for a valve of $4\frac{1}{2}$-inch maximum throw. Thus, the admission can be made equal to 90 per cent. of the full stroke, while very few engines are arranged for as little as 30 per cent. admission, 35 per cent. being the more usual minimum.

The outside-connected engine has taken the place of inside connections, owing to the frequent and expensive breakage of the crank-axles of the latter. The irregularities of the road, and the general use of sand, by which one wheel was often suddenly arrested while all were slipping, operated to break cranks very rapidly. This is not assigned as the most important reason for the preference of outside connections, although it has, more than anything else, induced that preference, in the United States.

There is no peculiarity in the adaptation of the engine to burning wood, as compared with that for burning coke, excepting that the blast-pipes are smaller, and that the chimney is arranged to arrest and retain the sparks. The proportions of the boiler are the same as are employed in England for burning coke; but as American boilers are built of from $\frac{1}{4}$ to $\frac{5}{16}$-inch iron, and as thin iron is used instead of copper for fireboxes, the tubes are almost always of copper, as they are found to remain tight better than brass under all the contingencies of rough setting and hard work.

A considerable advantage is found in the equalizing levers between the springs, especially on rough roads.

Cast-iron wheels are used for cheapness, and also for another reason, in the case of truck-wheels, as in these the flanges of chilled iron are not so rapidly cut by the friction on curves. In driving wheels, the centre, or "spider," for a 5-feet wheel to carry $4\frac{1}{2}$ tons, will weigh 1800 pounds and upwards. On some lines cast-iron chilled tires are largely used.

Full-stroke pumps are found to answer every purpose, where air-vessels are provided on both the suction and forcing sides. They fill surely and work easily, as to the pipes and joints.

To employ still more of the adhesion, and to distribute still more the weight on the rails, engines with six and eight coupled wheels have been much employed. For very heavy traffic, like that of coals, and on very severe gradients, the ten-wheeled engine, having six driving wheels and a truck-frame, has obtained the preference over the plan of eight coupled wheels, and that of six coupled wheels, without a truck. The ten-wheel plan is preferred for engines of about 60,000 lbs. weight—45,000 lbs. being on the drivers, of which 7500 lbs. only are on each wheel.* Practically, there is a little variation of the weight distributed respectively by the separate pairs of wheels, but no more than is due to the difference in weight of counter-balances and other attached parts in the wheels themselves. For lines of sharp curvature, the six driving wheels of these engines are clustered closely together in front of the firebox. In some cases, the hind axle is placed immediately beneath the grate of the firebox. In others, the rear axle is behind the firebox, and those of the other driving wheels forward.

The six-wheel coupled engine has been made both with inside and outside cylinders. With inside cylinders, the front axle could be carried close up to the back cylinder-cover. With outside cylinders, if these were inclined considerably, to admit the front wheels underneath, the motion was irregular. On the other hand, if the cylinders were level, there was much more overhanging weight.

Here every care was taken to keep the weight back; the hind axle was placed closely to the firebox, the middle axle was placed well forward, the firebox was of good size and provided with wide water-spaces; the dome and pumps were placed behind; the front tube sheet was placed back some distance into the barrel of the boiler, and the cylinder projected beyond the smoke-box,—yet for all this the weight on the respective pairs of wheels was as follows:—

Forward wheels, ...	21,000 lbs.
Middle wheels, ...	18,070 "
Back wheels, ...	12,350 "
Total, ...	51,420 "

From all the experience upon American railways, engines without trucks are considered to strain the track. In the above case, especially, with $10\frac{1}{2}$ tons on the forward driving wheels, the track was badly strained, and relieving wheels have already been introduced under the front end of the engine.

Figs. 1, 2, and 3, Diagram-Plate I., show the dispositions of wheels of the three classes of engines already noticed. While upon this subject, the corresponding arrangement of other engines may be referred to. All of the figures, from 4 to 20 inclusive, of Diagram-Plate I., represent American engines, some of which are in considerable use, although but few, if any, more are being built.

Fig. 4 was the arrangement of the original $10\frac{1}{2}$-ton Norris engines. These engines had more than one-half of their weight on the drivers.

Fig. 5 shows the original Baldwin engines,—much of the later "Crampton" style. Deficient in adhesion, although with the truck-frame very easy on the track.

Fig. 6.—*Fig.* 4 supported behind the firebox.

Fig. 7.—The American "Crampton" engine, built in 1849 by Norris Brothers,—8-feet driving wheels, six 30-inch truck-wheels, cylinders 13 inches by 34 inches.

Fig. 8.—*Fig.* 6 with a truck-frame in place of the trailing wheels. Built by Winans in 1849. 7-feet wheels.

Fig. 9.—Hinkley goods-engine, of from 1840 to 1846, $4\frac{1}{2}$-feet wheels, 6 feet centres.

Fig. 10.—Baldwin goods engine, $3\frac{1}{2}$ to 4 feet wheels, 7 feet 6 inch to 9 feet centres. Date, 1842. Still built occasionally.

Fig. 11.—Baldwin goods-engine, as above, except wider spread of wheels.

Fig. 12.—Reading Railroad burden-engine,—six 46-inch driving wheels and one pair leading wheels, 18 × 20 inch cylinders, about $11\frac{1}{2}$-feet centres.

Fig. 13.—Baldwin goods-engine, $3\frac{1}{2}$ to 4 feet wheels, 11-feet to 13-feet centres.

* In the state of New York, 2000 lbs. are a ton. The same standard is adopted, to a greater or less extent, in other states. In speaking of the weight of engines, in tons, the standard of 2000 lbs. is to be understood.—Z. C.

Fig. 14.—Baldwin goods-engine, as above, excepting greater spread of wheels.

Fig. 15.—Winans' burden-engine, 43-inch drivers, 11 feet 3 inch centres; 19 by 22 inch cylinders. Three hundred or more are running.

Fig. 16.—Baldwin's goods-engine, with hind driving axle under firebox. An engine of this pattern, 16 × 22 inch cylinders, 42-inch wheels, has drawn 293 loaded coal-cars,—about 2400 tons of 2000 lbs., at five miles an hour on a level.

Fig. 17.—Baltimore and Ohio R. R. ten-wheel engine, 50-inch drivers, 28-inch truck-wheels, 19 × 22 inch cylinders.

Fig. 18.—Baldwin's ten-wheeled engine, with hind driving axle under firebox, 49-inch wheels, cylinders 19 × 22 inches. Whole weight 61,000; 42,500 lbs. on drivers. This engine has drawn 847 tons (of 2000 lbs.), in addition to its own weight and that of tender, up a gradient of 1 in 132 for several miles.

Fig. 19.—The "Centipede" of Winans, 43-inch driving wheels, four 24-inch truck-wheels, cylinders 22 inches diameter and 22 inches stroke.

Fig. 20.—Passenger-locomotive by William Swinburne.

Fig. 21.—Tank-locomotive by A. F. Smith; 3½-feet driving wheels, 16½ feet centres, cylinders 12½ by 16 ins.

Fig. 22.—An engine built at Springfield, Mass. Needlessly complicated.

Fig. 23.—Tank-engine, by Danforth, Cooke, & Co., 11 by 15 inch cylinders, 4½-feet wheels, and pair of 26-inch leading wheels with swivelling truck under tank.

Fig. 24.—Engine by Norris Brothers, for New York and Erie Railroad, 7-feet drivers, connection made to back pair, 7-feet wheels; boiler but one-half large enough.

Fig. 25.—Engine by Zerah Colburn, for Delaware and Western Railroad, 4-feet wheels, boiler 4 feet 3 inches diameter, with 15½ feet tubes; firebox extending 8 feet in width across the track (6-feet gauge), giving 30 square feet of grate for anthracite coal. This enormous grate has since been further enlarged, being now 6 feet long and 7½ feet wide—45 feet of area for an 18 × 24 inch cylinder.

Fig. 26.—Six-wheel combined engine of Boston and Providence R. R. Inside connection.

Fig. 27.—Engine by Baldwin, for Vermont Central Railroad; "Crampton" pattern, excepting swivelling truck in front.

CHAPTER III.

Materials Employed in American Locomotives.

Cast Iron.—The castings for American locomotives are usually made of the domestic iron. The iron ores of the country are mostly either magnetic or hematitic. They are rarely or never found in the coal formations, a circumstance somewhat favourable to the strength of the manufactured product. When found within a moderate distance from coal, the American iron is apt to contain sulphur, and thus to incline to a red-short quality. Arsenic is also liable to be present in such situations, even in sufficient quantities to give a garlick-like smell to the iron when melted, and causing red-shortness also. Phosphorus, by which the iron is rendered cold-short, is also met with. Red-short and cold-short irons, mixed in the cupola-furnace, tend to neutralize their impurities and to make a good iron. Even the richest ores require mixing to produce the strongest iron, and in wheel-founding especially, the American founders pay very careful attention to mixing.

Most American irons are made either with charcoal under a cold blast, or with anthracite coal and hot blast. The best irons are invariably of the former manufacture, while the latter are superior in strength to the varieties made with American bituminous coal or coke. The anthracite irons have a strength of from 16,000 to 22,800 lbs. to the square inch, occasionally rising to 29,000 lbs.

Among many American founders, a considerable degree of attention is being paid to secure the best quality of castings. This is obtained by mixing, by keeping the blast dry—sometimes by passing it over muriate of lime, which absorbs its moisture, and by making the moulds as smooth as possible, so that the casting shall not require to lose much of its surface-iron in finishing. The most important castings, as cylinders, are made usually in loam, while other castings requiring great strength are made either from iron, slightly boiled in an air-furnace, or with a mixture of from ten to fifteen per cent. of wrought iron. For wheels, however, the latter varieties of iron have too much shrinkage,—often three-sixteenths of an inch in a foot.

The casting of chilled wheels is an extensive and peculiar branch of American iron-founding. The best mixtures of such irons as are at hand, or which may be procured, require often very protracted experiments and much skill for their determination. An iron is required which is not only strong, but which will "chill" evenly and shrink but little. Few if any single varieties combine these qualities. Some of the strongest irons shrink three-sixteenths of an inch per foot. The "chill" (produced by pouring the iron while in fusion into an iron mould) should penetrate to the depth of about half an inch everywhere on the surface of the tread of the wheel, and should blend with the soft iron beyond it in such a manner as to leave no distinguishing line of separation.

To guard against the strain, produced by the unequal shrinkage of the nave and rim of cast-iron wheels, has been the subject of much ingenuity. The rim being thin and being poured against an iron mould, contracts rapidly upon the still fluid nave, which, in cooling subsequently, tends to tear away from the rim. When all cast wheels were made with spokes, the nave was divided into three separate segments, three slots or openings of half an inch in width each running through the whole length and thickness. After the wheel had cooled, these openings were filled either with lead or with dowels of iron, and two strong wrought-iron bands were shrunk one upon each projecting end of the nave. The single and double disc or plate forms being respectively adopted, these were variously warped, always with the object of accommodating the plate to the strains which came upon it in cooling. These forms have been the subjects of something more than a hundred patents. More recently it has been sought to cool the wheel equally in all parts. At Whitney's Wheel Works, in Philadelphia, the wheels, as soon as they have

taken their "set" after pouring, and while they are yet red-hot, are taken out of the flasks and deposited in deep pits of brickwork, previously heated red-hot; and where, all access of air being excluded, they are from three to four days in cooling, and must necessarily cool equally fast in all parts. This treatment so thoroughly provides against all internal strain in the wheel, that while an ordinary solid-hub spoke-wheel broke of itself on being cooled suddenly in the open air, a wheel from the same pattern, but cooled in the "annealing kilns," did not break even after a ¾-inch hole had been drilled through the width of each of five spokes, leaving only a film of iron of less than ⅛ inch thickness on each side of the hole. It had been supposed by many that the process of very gradual cooling would injure if it did not destroy the chill. The result proves that the chill retains its hardness perfectly. It is believed that the peculiar arrangement of particles, recognized as the chill, occurs at the moment the iron enters the solid state,—that is, on the "set" of the casting, and that no heat below that point, subsequently applied, can draw the chill,—in the same manner that steel, hardened to one colour, will not lose its temper at any lower heat.

Driving wheels of 5 feet diameter are occasionally cast whole and treated as above described. The usual sizes of chilled wheels are 30 and 33 inches for engines, and 33 and 36 inches for cars. It is a defect of chilled wheels, that beyond any liability they may be under as to breaking, they cannot be cast of exactly equal diameter, nor always perfectly circular. If they chance to be bored out eccentrically, or should the chill be unequally hard and thus wear faster in one place than elsewhere, much harm will ensue. The chill will always soften where the wheel has been allowed to slide, and the breakmen are strongly cautioned against locking the wheels with the breaks, as, a flat place once formed in the chill, the wheel will always turn to it when the breaks are again applied, and will thus be soon destroyed. Cast wheels, besides their cheapness, costing but from £2, 10s. to £3 each ($12 to $15), have an advantage, upon very rough lines, over wheels with wrought-iron tyres, inasmuch as the latter are abraded in the flanches, often to such an extent that the wheel is led off the line. The hardness of the chilled flange resists this action quite effectually. The cast wheels, cooled by Whitney's annealing process, have each a single plane disc, stiffened with straight radial ribs on the back. Their weight is about 400 lbs. for the 30-inch, and 430 lbs. for the 33-inch wheels. The other varieties have two discs, convex on their outer sides, the nave being divided into two portions, attached respectively to the discs. The usual service of these wheels is from 50,000 to 100,000 miles run, and their usual load is two tons each.

Driving wheels, although cast usually to receive wrought-iron tyres, require considerable care to prevent being strained in cooling. These wheels are made almost always with radial spokes. The nave must be solid, hence the rim is quite commonly divided by slots, into three segments, which, as the nave contracts, can draw towards each other without strain. In such wheels, the counter-balances are cast whole with the wheel,—wrought-iron dowels are inserted in the openings in the rim, and the tyre then shrunk on, which thus binds the whole firmly together.

Many of the best cast-iron driving wheels are now cast with hollow spokes; and sometimes even the main nave, and that of the crank-pin also, are cored out hollow. In such cases the rim is cast whole, the distribution of the iron in the nave being relied on to equalize the shrinkage.

In a few railway shops, cast-iron work exposed to wear is being case-hardened, the process being found not much more difficult than that of case-hardening wrought iron. Prussiate of potash, saltpetre, and sal-ammoniac are powdered, and mixed in equal parts. The article to be hardened is made to take a red heat in the fire, and is then well rolled in the above mixture, so as to be entirely covered by it. It is then, while yet hot, placed in a bath containing two ounces of prussiate of potash and four ounces of sal-ammoniac in every gallon of cold water. When cooled, the induration on the surface will resist a file.

In several railway repair shops, broken castings, as cylinders, are mended by fusing fresh metal upon them. If there are cracks only in the casting, these are opened out, by a drill, to channels of two inches width, so as to leave room for pouring in sufficient iron to repair the break. A wooden pattern is then made to fill the space cut or broken out from the cylinder. The casting is then bedded in sand, nearly to the lowest point of the fracture. If this is lengthwise of the cylinder, the latter is placed on its side, and inclined a little, so that one end shall be lower than the other. An iron support, as a piece of boiler plate, is put through the cylinder, below the lowest edge of the break, and all the space between this support and the wooden pattern is rammed closely with sand. A flask is then arranged to close upon the upper part of the cylinder, or that part above the sand in which the cylinder is first laid. In this condition, a charcoal fire is made within the cylinder, below the internal body of sand supported upon the piece of boiler plate. The cylinder is thus heated and considerably expanded, and this heat assists the melted iron, afterwards poured in, in overcoming the temperature of the broken edges of the casting. A sufficient number of "runners" is left through the flask, above the cylinder. Where the weight required to fill the break would be perhaps 50 pounds, as much as 1400 pounds are run continuously through the mould. This flow of iron, going on successively through the different runners, fully unites the new iron with the old casting. This process is carried out at a cost of from £4 to £6 ($20 to $30), including taking down and re-hanging the cylinder. The cylinder, if mended in the bore, requires only to be re-bored as it leaves the sand, or squared up where the flanges have been mended.

Cast iron, as a material of construction, has many peculiar applications in American locomotives. The cross-heads are very commonly of cast iron, without brass linings, and work upon wrought-iron guide-bars, not case-hardened. The bars are sometimes bolted in place with a few thicknesses of sheet tin at their supports, which may be taken out as the cross-head wears, although the ends of the guide-bars may be filed down from time to time, for the same purpose. Cast iron is almost always employed for eccentric straps, where, as indeed in most situations where there is not much friction, it wears better than brass. Wrought-iron eccentric straps are scarcely ever made. Cast-iron links (in the link motion) have

been occasionally made, and, although heavy, they wear quite well. Cast-iron rocking arms are sometimes met with also, but never in the better class of work. The axle-guards of American railway cars are always of cast iron, and for engines, cast-iron "jaws," or "pedestals" (axle-guards), have been extensively used. A cast-iron axle-guard, with 3 inches width of bearing, will wear as well as one of wrought iron $4\frac{1}{2}$ inches wide. Indeed the wrought-iron "jaws" of the best engines have generally cast-iron wedges, serving also as a lining upon their wearing faces. The foot-plates are made almost always of cast iron, and the bases of the domes, sand-box, and chimney are cast also. Occasionally the steam pipes are made of cast iron. The grate-bars are always cast. Wrought-iron ferrules or thimbles, for the tubes, were formerly used by all American builders, but they seldom sufficed to keep the tube-sheets tight. Cast iron, as a material for ferrules, was first adopted by Mr. William S. Hudson (now superintendent of the Rogers Locomotive Works), in 1850. Cast iron dilates permanently by heat, and is thus more likely to remain tight when used in ferrules. None others than those of cast iron are now used by American builders. Cast-iron tyres are extensively used upon some railways—they are $3\frac{1}{2}$ inches thick, chilled upon the wearing surface, and are held upon the wheels by bolts passing transversely through the rim, whereby the tyre is drawn on tightly, but without strain. The tyre is put on cold, as it would be broken in "shrinking." The adhesion is certainly something less than that of wrought iron, but the wearing surface, while it lasts, is perhaps better, and for engines used about stations, and for heavy burden engines at slow speeds, cast-iron tyres are found to serve a very good purpose. Cast-iron chilled boxes, or car axles, are used upon one or two railways.

Wrought Iron.—English iron has been very extensively used in American railway machinery, and must for a long time continue to be so employed. Of the American merchant iron, made generally with anthracite under a hot blast, there is little which will not bear 25 tons per square inch, while much of it has a strength of 30 tons (of 2000 pounds).

Very few careful experiments have been made upon the strength of American boiler-plate, since those made about fifteen years since by the Franklin Institute. These gave the following results (the tons are of 2240 pounds):—

Process of Manufacture.	Rough edge bar.	Edges filed uniformly	Notches filed into bar on each edge
Piled Iron, ...	23·7 tons.	25 tons.	28·24 tons.
Hammered Iron,... ...	21·2 „	24·81 „	26·1 „
Puddled Iron, ...	23·37 „	22·8 „	27·87 „

The inherent irregularities, even in the best specimens, whether of rolled or hammered iron, were seldom found to fall short of 10 or 15 per cent. of the mean strength.

At the time these experiments were made $\frac{3}{8}$-inch iron was used in 36 to 40 inch boilers, to carry 90 to 100 lbs. per square inch. Now $\frac{1}{4}$ to $\frac{5}{16}$ inch iron is used for boilers of from 43 to 50 inches diameter, to carry 120 to 130 lbs. of steam, and cases are not wanting of 200 pounds pressure in boilers 48 inches in diameter and of $\frac{1}{4}$ inch thickness. These are always single-riveted.

The fireboxes of wood-burning engines are made wholly of iron, the sides very generally of $\frac{1}{4}$-inch plates, which are found to be less liable than thicker iron to blistering from the heat. The tube-plates are $\frac{5}{16}$ or $\frac{3}{8}$ inch thick, the crown sheets $\frac{5}{16}$ inch. Lowmoor or Bowling plate is generally preferred for soundness,—American iron for strength; and the best English plate is therefore quite generally preferred for inner fireboxes, and for flanged sheets.

The various heavy forgings for American locomotives, with the exception of the tyres, are very generally made from scrap iron. Cranked axles, where made to replace those which have failed (no new engines are now built with cranks), are variously made. The best are first got out in a slug, perhaps 4 feet long, and nearly a foot square, which is then swaged down in the middle and at the ends. The throws thus "roughed out," are then worked into shape and are afterwards set at right angles to each other by twisting the central part of the axle. In a crank made in this manner, the grain runs around the throws, which are thus less likely to split through. Other cranks are made by getting them out in a flat slab, of the extreme length, width and thickness of the finished forging. The iron between and outside of the throws is then cut out in a slotting machine, after which the throws are twisted at right angles to each other, in the usual manner. Cranks thus made are liable to split off through the cheeks or throws. The least reliable mode of making cranks, that of welding the throws, as separate masses upon the shaft, is now nowhere practised in American forgings. Upon the New York and Erie Railway many of the cranks have had strong wrought-iron straps shrunk around the cheeks, as in the Vale of Neath engines, Plate XXXI.

Axles are made with different degrees of care at different forges. Scrap axles are generally drawn out under the hammer at two heats. At some of the forges where new iron is puddled for axles, the blooms are first squeezed by a rotary squeezer, then piled, heated, and rolled, twice in succession, and finally heated and swaged to shape. An excellent but expensive axle is made also from cold blast, charcoal iron, shingled with a hammer, then piled, heated, and hammered three times in succession, and finished with one swaging heat. Considerable difference of opinion prevails as to the relative merits of new iron and of scrap for axles. Each is liable to accidental defects, but in large quantities both are used with perhaps like degrees of satisfaction. Scrap iron is necessarily of very variable quality. In some cases, large quantities of the cuttings of new iron may be had; in others, choice iron, like carriage-tyres, may be obtained, partly worn,—while in other instances a scrap-pile may comprise bits of old and new, hot short and cold short, burnt and raw, and other opposite qualities of iron, some of which may burn while others are welding, or while the first are welding the latter may not unite at all. Lumps of cast iron or of steel may chance to be hid in the pile. The rust and sand with which scrap iron is often coated are also unfavourable to sound welding. So in the pile the scrap requires to be very well drawn down to secure a uniform grain, as the several pieces in the pile may lie with their grain in different directions, so that while some are drawn others are upset. The chances, however, to which all irons are subject of being either burnt or else worked at too low a heat, render the practical comparison of new iron and scrap forgings quite difficult. Much bad work is done in both materials.

The manufacture of wrought-iron engine tyres is carried on at but two or three establishments in the United States. At the largest of these works, the mode of manufacture is as follows:—The pig metal is made from a hematite ore, smelted with charcoal under a cold blast. It is puddled with a free burning bituminous coal. The blooms from the puddling furnace are shingled under a hammer. These being of about 175 lbs. each, are drawn out roughly into a "loop," say 16 inches long, 10 inches wide, and 4 inches thick. Two of these are placed together and drawn down under a hammer into a rough bar, say 5 feet long and 4 by 4 inches. All heats other than that in puddling are with anthracite coal. The bar just drawn is cut in two, and ten or twelve of the slugs so made are laid up in a pile, the separate pieces being kept half an inch apart to admit the heat to the centre of the pile. An iron slab of about 3 cwts. is laid upon the top. The whole pile of some 16 cwts. then takes a sound heat, and is closed up under a steam-hammer, having a head of 5½ tons, falling 5 feet. The pile is again heated and drawn under the same hammer, to a slug of, say, 5 feet length and 15 inches diameter. This is yet again heated and drawn under the same hammer to a rough bar of, say, 8 feet in length and 8 ins. square, and which, being then cut in two, makes two tyres.

Each of the slugs made in the last process is now taken to another fire, and thence drawn again under a lighter hammer, one end at a time, each end being heated separately. It is then once more heated and drawn under the light hammer (2½-ton head) into rough tyre bar, but of about half an inch greater thickness than the tyre is intended to finish. The bar is then bent and welded, the single weld being made with one V-piece and two binders. The tyre is now about 9 inches or 1 foot smaller in diameter than it is intended to finish. It is next heated evenly in a shallow furnace and taken to a rolling machine, where it is rolled out to size and down to thickness, when it is finished.

In making connecting rods, the "stub ends" are sometimes drawn out solid from a pile, and at other times welded merely upon the ends of a plain bar. Of course the former mode of making is much the best. Piston-rods, to prevent their becoming grooved by wearing in the packing, are sometimes twisted in forging. The iron for tyres was at one time similarly twisted, but, as might be supposed, the wear was unequal, and the process of twisting was abandoned.

Iron tubes are coming into extensive use, particularly for coal-burning engines. They are made at two establishments in the United States, besides what are imported of English manufacture. The American tube has what is called a "safe end," a few inches of iron at one end of the tube having its grain around the circumference, besides being carefully annealed. This is a protection both in caulking and in the expanding process (by which most iron tubes are now set).

Various Materials and Applications.—Copper is the most usual material for tubes. Its cost is about 25 per cent. more than that of brass, but while the latter material becomes brittle under the operation of caulking, copper has a malleability by which it can be readily tightened in the tube-sheets without sustaining any injury. For this reason, copper ends are often brazed upon iron tubes. For coal-burning engines, copper, for either the tubes or the furnaces, is too soft,—the flying particles of coal cut it rapidly away. Where copper is used at all for the furnace it is only for the lower portion. Tubes are made from various thicknesses of copper, the thickest being No. 12, the thinnest No. 15 or 16.

For axle-boxes, brass lined with anti-friction metal is largely used. Many of the best builders, however, will not use white metal linings, as they are so rapidly destroyed by the smallest quantity of dust finding its way to the journal. Various materials are used for axle-boxes. A composition of 97½ parts of zinc with 7½ parts of copper has been considerably used, and with good success. The box is cast entirely of this metal, no separate lining being employed. The lubricating material employed is always oil and never grease. Old type-metal, at a cost of 5*d.* (10 cents) a pound, has been very successfully used for axle-boxes. Upon the Baltimore and Ohio Railway, cast-iron boxes, chilled upon their bearing-surfaces, are much used for freight car axles. Cast-iron boxes, lined with glass, have been used, but without much success. The glass was poured in a fused state into the cast-iron shell, and boxes so made have occasionally retained an excellent wearing surface after many months' use. The best brass boxes are made of a composition of 9 copper to 1 tin. In Baldwin's engines, nearly all the brass work is of this expensive but excellent composition. For small boxes, like those of valve-stems, wrought iron, case-hardened, is much used,—the wear being almost inappreciable.

Cast-iron valves are occasionally made with brass faces; and brass rings, for joints, sometimes form part of the castings of iron pump barrels. In such cases the brass portion of the casting is first made in a separate mould, Its composition is quite hard, say 9 of copper to 1 of tin. The cast iron is then poured slowly upon it,—in the case of large valves, several "gates" are made in the mould, through which the iron is poured as nearly equally as possible. The iron unites perfectly with the brass, so much that no galvanic action goes on, such as is noticed where separate surfaces of iron and brass are exposed in contact to each other. In iron pump castings, where separate brass rings are employed for making the joints, the iron is occasionally found to become eaten in small holes.

Cast-steel springs are being adopted by many American builders. The volute springs, thus far used in the United States, have been made of best cast steel. It is not settled whether the volute spring has any advantage over the common form, excepting that it occupies less space. India-rubber springs were at one time tried under engine trucks, and were considerably used for tenders. In the former application, they utterly failed, both by crushing and by settling into a rigid mass. Their use under tenders has been also entirely abandoned. They are still employed on many lines as car springs, and do great damage to the permanent way and machinery, by their short hard action, besides often freezing quite hard in winter, and softening in very hot summer weather. India-rubber packing, by the sulphur which it retains from its manufacture, has a corrosive action upon the stuffing-boxes, bolts, &c., while for machine belting it gives trouble also from stretching, from breaking, and from rotting wherever oil chances to get to it. For belts requiring to be frequently shipped

from one pulley to another, and exposed thereby to abrasion upon the edges, india-rubber is wholly inadmissible. Compressed air-springs have been occasionally, and were, indeed, at one time quite generally, used for railway carriages. They rode delightfully, but required far too much trouble to keep them properly packed. For the coal waggons of the Reading Railway, the springs are mostly of wood: two planks of ash timber, each 8 feet long, and 6 by 2 inches section, being bolted together, fastened at their ends to the framing of the waggon, and having the axle-boxes bolted to their under sides.

In the external finish of the engine, bright planished Russia iron is in every case used for covering the barrel of the boiler. This iron has a beautiful surface, and requires only to be rubbed with a little oil to protect it from rusting. The bands, by which this covering is held to the boiler, are always of polished brass, sometimes richly moulded. The roof of the firebox is sometimes covered with thick felt, with a polished brass casing outside. The domes (there being two on many engines) are almost always covered with polished brass, generally of a rich architectural design. The cylinders (where outside of smoke box) with the cylinder covers and the valve-chests are in most cases similarly covered. Brightly polished surfaces, as is well known, radiate less heat than those which are dark and rough; hence there is a decided advantage in the use of the showy brass work of American engines. The engineman's house, shown on Mason's engine, Plate XLVII.*, is very frequently of an elaborate architectural character, rich varieties of wood, as rosewood, mahogany, black walnut, "bird's eye" maple, satinwood, &c., being employed in its external decoration, while the windows are of heavy plate glass.

DETAILS OF CONSTRUCTION.

Boiler.—The structural peculiarities of American locomotive boilers are shown in Plate XLVI.* The inner firebox is of the usual form; the roof of the outside fire box being raised from 9 to 12 inches above the cylindrical portion of the boiler. In other examples two steam domes are employed, one being placed midway or near the front end of the barrel. The sections forming the barrel are very commonly arranged in the manner of the rings of a telescope, that next the firebox being of the largest diameter. In this case the top of the boiler is levelled, the inclination of the under side serving to assist the movement of solid matter towards the water-spaces around the firebox. Angle-iron is no longer used in the construction of American boilers, all angular junctions being made by flanges formed on the sheets. The smoke-box is often made cylindrical as a continuation of the barrel of the boiler. For stiffness in fastening the cylinders, the smoke-box is usually made of heavier iron than the barrel, and in some instances the forward tube-plate is carried into and fastened in the smoke-box. The tubes are now usually arranged in vertical rows to facilitate the circulation of the water.

The working conditions of American railroads are such as to require a larger expenditure of steam, in a given time, than the average in English engines. American lines offer greater resistance, both in gradients and curves, and the trains run upon them are heavier than in England. To generate this additional quantity of steam, in boilers no larger than those generally used in England, the draught is not only forced to a greater extent, but additional precautions are taken to prevent priming. The elevated roof of the outer firebox and the "double domes" —from each of which one-half of the whole working supply of steam is drawn—afford additional steam-room, besides protecting and equalizing the delivery of steam to the cylinders. The sloping gusset, by which the roof of the firebox is connected to the barrel of the boiler, gives additional steam-room also, as well as a strong and simple fastening, and adds to the convenience of making internal examinations of the boiler. As to the position of the single dome, there is no settled practice: when placed over the firebox, and having both safety-valves seated in its cover, there is unquestionably a tendency to priming. At the same time, also, the roof of the outer firebox is, next to that of the inner firebox, the weakest part of the boiler. In some cases where a single dome, of very large diameter—say 30 or 36 inches—is made, the opening through the barrel of the boiler is of no more than 18 inches diameter, this size giving ample opportunity for making internal examinations through the dome, whilst the boiler is not seriously weakened. As in England, a considerable number of engines have been made and successfully worked without a steam-dome; a perforated or slotted steam-pipe being employed to draw the steam alike from the whole length of the boiler. This arrangement, as long as it can be relied upon for the supply of dry steam, is obviously the most simple and desirable, inasmuch as domes weaken the boiler, besides being heavy and expensive, and presenting additional radiating surface. Those who adopt and advocate the use of the perforated steam-pipe are in every case able to furnish instances of their successful use; notwithstanding which, they are no nearer general adoption than ever. Among some of the most successful examples of American locomotives, now working without steam-domes, may be mentioned several of those made by William Mason & Co., as well as some of the earlier engines made by Rogers, Ketchum, and Grosvenor, for the Erie Railroad. In Mason's engines the perforations in the steam-pipe are very small, decreasing in size also towards the smoke-box. In Rogers' engines the openings were a triple row of slots, each 3½ inches long, ¼ inch wide at the firebox, and ⅛ inch wide at the smoke-box end. In both cases the pipes were placed as nearly as possible to the top of the barrel of the boiler. In nearly all American engines, the throttle-valve, or regulator, is placed in the smoke-box, so that the perforated pipe possesses no advantage nor disadvantage in that respect. The throttle-valve, when placed in the smoke-box, is easily accessible, although it is more likely to become dry and stick than when placed within the boiler. The steam-pipe, in the former case, can be made large and thin, without any danger of collapse. A large steam-pipe forms a reservoir by which the supply of steam to the cylinders is equalized, and priming consequently diminished. And the steam in the steam-pipe, when the throttle-valve is shut off in the smoke-box, is retained in the boiler instead of passing into the cylinders, although this steam is condensed and remains as water in the pipe when the boiler is cooled.

The materials used in the construction of American boilers have been before mentioned, although it may be repeated here that the firebox is almost always of iron, the thickness of its sides being from $\frac{1}{4}$ to $\frac{5}{16}$ inch, and of the crown plate $\frac{5}{16}$ to $\frac{3}{8}$ inch. The lesser thicknesses are generally preferred, as insuring greater soundness in the iron. The sides of the firebox, where properly stayed, are, as is well known, the strongest parts of the boiler. The plates of the barrel of the boiler, however, even for diameters of 48 inches, and pressure of 130 lbs. per square inch, are often no more than $\frac{1}{4}$ inch in thickness, rarely more than $\frac{5}{16}$ inch.

The inside firebox is sometimes made with a separate crown-plate, flanged downwards on each of two sides; whilst in other cases the side plates are bent and continued sufficiently, by meeting in a seam of rivets over the centre of the firebox, to form the crown without a separate plate. In the first case, the crown or roof stay-bars are placed transversely across the firebox, care being taken that their ends rest fairly on the upper edges of the side plates; whilst in the other case, the stay-bars extend fore-and-aft, and rest at their ends on the angles of the flanges in the tube and door plates. Continuous longitudinal stay-rods, extending from the back or door-plate to the smoke-box tube-plate, are rarely used. The stay-rods from the back plate extend diagonally to the inner surface of the barrel of the boiler, to which they are rivetted, the smoke-box tube-plate being stayed in a similar manner. With the raised roof of the outer firebox and the sloping gussets by which it is connected to the barrel of the boiler, a weak place is left in the sides, just forward of the firebox. In the best constructed boilers, the forward transverse roof stay-bar is extended at its ends, and rivetted through suitable lugs to the outer firebox, a cross stay-rod is fastened in just above the tubes, and all the joints about this part of the boiler are made with double rows of rivets. The roof of the inner firebox, in addition to the bars, is stayed by vertical links or rods, rivetted at their upper extremities to the roof of the outer firebox, or to the inside of the dome. Considerable difficulty has been experienced on various lines, from the corrosion or crystallization of the stay-bolts connecting the sides of the inner and outer fireboxes. In some instances, these bolts, although believed to have been originally made of the best iron, were found to have become so corroded or so crystalline in texture, as to have suddenly given way when the engine was at work; and some cases of explosions have occurred, apparently from the failure of these bolts, those not actually broken in the explosion snapping off afterwards, under a light blow, as if they had been made of cast iron. By some, this result has been attributed to a supposed repeated strain—a partial bending and unbending of the bolt—every time the firebox is heated and cooled; the expansion of the inner firebox being supposed to be more than that of the outer firebox. This hypothesis is apparently strengthened by the fact that the upper rows of stay-bolts, which, in the case of such expansive action, would suffer most, are actually those which oftenest give way. For this reason, the stay-bolts, in some cases, are turned down smooth between the plates, and smallest at the middle of their length, their form being intended to permit some amount of lateral strain without permanent injury.

For wood-burning engines, the water-spaces around the firebox are in many cases very narrow—sometimes no more than $1\frac{1}{2}$ inches at some places on the sides; 2 inches is a common width on each side. In coal-burning engines, 3 inches clear space appears to be the least to which the protection of the plates can be intrusted. The known difficulty of circulation in deep, thin water-spaces has occasionally led to the trial of expedients for promoting the movement of the water. In some of the engines of the Hudson River Railroad, a plate of thin iron has been inserted in the middle of the water-space, and parallel with the side-plates. The ascending currents can thus rise in contact with the heated walls of the firebox, without obstructing the descending currents on the outer side of the partition. The conducting power of iron plates is such that it is believed that no degree of heat on one side could burn the plate while there was a constant access of water to its opposite surface. In cases where the sides of fireboxes are burned out, there is reason for believing that the circulation of water around them is obstructed, in which case, in addition to the actual injury to the iron, there must be a considerable loss of fuel. Mr. C. W. Williams, in his *Combustion of Coal*, has mentioned the case of a marine boiler, with very deep, thin water-spaces, wherein, although a gauge-cock at the top showed a proper level of water, another cock, tapped into the water-space at some distance below, discharged dry steam only. To give a free passage for the descending currents of water, seeking to take the place of that, the specific gravity of which has been already diminished by heat, and which is, therefore, rapidly ascending upon the heated sides of the firebox, Baldwin & Co. have, in some of their coal-burning engines, employed a pair of 2-inch pipes, connecting the under side of the barrel of the boiler with the bottom of the water-space, on each side of the firebox. Water-spaces of ample width, and, still better, increasing gradually in width towards the top, answer every purpose, however, and entirely obviate the necessity of the contrivances just described.

The tubes of wood-burning engines are generally made of copper of from No. 13 to No. 16 gauge. Brass tubes are used to some extent, and with care in setting, and in the management of the engine afterwards, they appear to answer very well. They will not withstand the action of caulking with the same readiness as copper, besides which they are more readily injured by overheating. Iron tubes are extensively used, especially for coal-burning engines. Where the firebox-end is made with a piece of annealed iron, with the grain around the circumference, instead of along the length, and where the ends are carefully and accurately set, iron tubes give much satisfaction. There appears to be little doubt among those who, from experience, are best fitted to judge, that iron tubes transmit heat equally as well as copper or brass, whilst their stiffness is an important circumstance, inasmuch as it tends to keep them tightly in the tube-plates. Ferrules, or thimbles, are used only in the firebox tube-plate in American engines; and with iron tubes, excepting where copper ends are brazed upon them, no thimbles are ever used. The thimbles are now made, moreover, of cast iron, as that material dilates permanently by heat, and is more likely than wrought iron to remain tight in the tubes. Cast-iron thimbles require to be a trifle thicker than

wrought-iron, and by so much offer a slightly increased obstruction to the draught. The tubes are being generally arranged in vertical rows, so as to present the least obstruction to the circulation of the water. For this reason also they are now only rarely placed nearer than ⅝ inch apart in American engines. It is stated upon the authority of some of the most experienced locomotive superintendents, that engines with a large number of small tubes, crowded closely together, have been found to steam more freely when one of the middle vertical rows was plugged so as to shut out the heat; thus increasing the effective duty of the outer tubes, and giving increased opportunity for the descent of the cooler currents of water. Mr. George S. Griggs, of the Boston and Providence Railroad, has mentioned an instance in which an exploded boiler was found to have been burned in the tubes, about the centre of the whole mass of tubes, whilst those at the top were entirely sound, and without scale. This would argue the dispersion of the water from the hottest portion of the tubular mass, where also the access of water was most difficult. This circumstance assists to confirm that already referred to as having been mentioned by Mr. Williams. Whilst the tubes were formerly, very generally, no more than 1¾ inch, they are now made, in most cases, 2 inches in diameter. It appears to have been well settled that, other things being equal, 140 tubes 2 inches in diameter will make more steam than 160 tubes of 1¾ inch—the same surface being presented in each case. The sectional area of tube-opening is of course greater as the tubes are enlarged, whilst there is also additional opportunity for circulation as their number is reduced.

The chimney of the American locomotive is one of its most characteristic features. Apart from the eagerness of its combustion, wood suffers a rapid decrepitation when burned, so that when under the influence of a strong draught, a large part of its substance is shot forth in showers of sparks. To arrest and retain these without seriously impeding the draught, has been the object of much ingenuity. One of the earliest, and, as experience has proved, the best arrangements for the purpose is that known as the "bonnet pipe," shown in each of the sections of American engines, Plates XLVII.*, &c. An inverted conical deflector, having a rolling edge like the rim of a tea-saucer, is placed a few inches above the mouth of the ordinary chimney. This deflector inverts the draught, the sparks by their weight remaining in the bottom of an annular casing outside the chimney, whilst the steam and smoke rise and pass off through a wire-cloth screen, or bonnet, at the top. This form of spark-arrester was applied by William T. James, of New York, to an engine built by him, in 1833, for the Baltimore and Ohio Railroad; but it was not generally adopted until 1837, when its use was resumed by Thomas Rogers. Some years afterwards, French and Baird brought out a spark-arrester, in which a series of curved vertical vanes, or floats, were set up beneath the conical deflector, so as to give to the sparks a spiral, or tangential motion, sufficient to throw them against the sides of the outer casing, whence they fell to the bottom. The smoke and steam, in the meantime, rose through a series of wire-cloth rings in the top of the chimney. This form of spark-arrester retained nearly all the sparks, and was for this reason especially preferred on railways in the Southern States, where the sparks from the engine are so dangerous to cotton trains. The arrangement of the deflectors and wire-cloth screens somewhat impeded the draught however, and more recently, and since the adoption of various adjustments has permitted the enlargement of the exhaust-nozzles, and the consequent moderation of the draught, several of the Southern railways have returned to the use of the "bonnet pipe." Several other forms of spark-arresters have included the curved vanes to impart a centrifugal motion to the sparks, but the present practice turns chiefly in favour of the "bonnet pipe," which will doubtless retain the preference now given it, until coal shall have entirely superseded wood as a fuel in locomotives.

Framing.—The arrangement of framing usual in American engines is almost invariably that of two trussed beams, between the wheels, only inside bearings being employed. The English counterpart of this arrangement was that so long preserved by Bury, Curtis, and Kennedy. The main bars are generally 4 inches by 2 inches, laid upon their flat sides and bent downward, in front of the forward axle-guard or pedestal, nearly to the level of the axles. The legs of the pedestals are more generally welded (although they are sometimes bolted) to this bar, and their lower ends are connected together, and diagonally to the ends of the frame, by flat tension bars, forming a truss. The frame is braced to the barrel of the boiler by stiff braces at intervals averaging 3 feet. The object of this bracing must be considered as that of stiffening the frame rather than the boiler, which although of thin iron as compared with that used in English locomotive-boilers, is thus made to participate in the strains exerted through the running-gear. The propriety of this arrangement might be questioned, although in practice no conspicuous evidence of injury to the boiler is presented. The slab-bar frame, 8 or 9 inches deep and 1 inch thick, was adopted at an early date by the Amoskeag Manufacturing Company, and has been employed also in all the engines built at the Jersey City Locomotive Works. Its strength and simplicity, and the convenience with which such parts as are usually supported by the frame may be fastened to it, are likely to lead to its ultimate general adoption. In Baldwin's engines, lugs are forged upon the frame to receive the cylinder flange, and the boxes and pedestals, which, in addition to their fastening by bolts, are further tightened by keys. The extremities of the frame are always braced by diagonal braces to the ends of the boiler. The boiler cannot be considered as being rigidly fastened to the frame excepting at the smoke-box, between the stiffened sides of which and the frame the cylinders are firmly bolted. At the firebox-end a long angle-iron brace rests upon the upper side of the frame, to which it is confined by a strap extending over the whole length of the brace, and bolted down at the ends. Provision is made for the free expansion of the boiler, amounting to about ½ inch in the whole length. The same arrangement of angle-iron brace and strap is usually repeated on the tension-bar connecting the lower ends of the pedestals. The screw-bolts which fasten the angle-irons to the firebox are generally made to pass through the water-space, and are screwed and rivetted in the inner firebox-plate. In some cases, a nut with a concave face and a packing of canvas and red-lead is placed upon the bolt whilst it is being passed through the water-space, this nut being screwed tightly against the inner

surface of the outer firebox. The intermediate braces, fastening the frame to the barrel of the boiler, are bolted firmly to the frame, but while the braces next the smoke-box generally have their flat sides outward, those towards the firebox are placed with one edge outwards, so that they may bend slightly, and thus accommodate themselves to the expansion of the boiler. In the engines by the Boston Locomotive Works the intermediate braces are round columns. The braces are usually rivetted to the boiler through broad palms, although in some cases where the tubes are set before the boiler is put in the frame, the braces are fastened by screws entered from the outside. This mode of fastening has been followed in all the engines made by the Taunton Locomotive Manufacturing Company.

The fastening of the cylinders to the smoke-box and frame, so as to secure the greatest stiffness and permanency with the least weight, is a problem of much importance, and requiring some little ingenuity for its solution; it being borne in mind that only outside cylinder engines are made anywhere in the United States. The want of a proper cylinder fastening in the outside connected engine kept that arrangement for a long time in disfavour, although since attention has been directed with more earnestness to the point, the highest conditions of strength, permanence, lightness, and convenience of arrangement have been attained. The cylinder fastening in the engines by the Rogers Locomotive Works especially fulfils these conditions. The smoke-box, of ⅜-inch iron, has flat sides, further stiffened by $\frac{5}{16}$-inch patches on the inside. The bottom is a flat plate of ½-inch iron, extending beyond the smoke-box to rest on the upper sides of the frame-bars. The "ring," rivetted within the forward edge of the smoke-box, and to which the cast-iron front is screwed, is of heavy iron, say 4 inches by 1½ inch, and a stout cross-bar is also put in to brace the sides laterally. In addition, two round diagonal braces extend, one from each lower outer angle of the hinder side of the smoke box up to the barrel of the boiler. The cylinder has a flat 4-inch flange resting upon the projecting surface of the ½-inch plate iron bottom, through which and through the main frame and under trussing bar, the whole are fastened by six 1⅛-inch bolts, accurately turned and driven into carefully reamed holes. The flange by which the cylinder is thus bolted, turns up also for nearly 15 inches upon the side of the smoke-box, to which it is also firmly bolted. The valve-face of the cylinder extends to and unites with this flange, and the steam and exhaust passages pass through it, so that the whole casting is rendered very stiff. The cylinder fastening of the Norris engines is much the same, excepting that the smoke-box bottom is formed by a heavy cast-iron plate, with vertical flanges turned up on the inside of the smoke-box.

With the round smoke-box of ⅜-inch iron, the "saddle" employed for fastening the cylinders in Mason's engines is strong, and is not objectionably heavy. This saddle is a kind of cast-iron box, fitting between the frame-bars and to the curve of the smoke-box, to which it is bolted. The saddle rests upon, and is planed flush to the top of the frame as well as to its outer edges, whilst a flange is turned down from the under side of the saddle and planed to fit the inner sides of the frame. The cylinder is very strongly bolted to the outer vertical face of this casting, and through a broad horizontal flange also to a seat on its upper surface. All the bearing surfaces are accurately planed to each other, iron to iron, no chipping pieces being used. The exhaust-passages from the cylinders are continued through the saddle to the bottom of the smoke-box. The weight of this saddle, in the rough, for an ordinary narrow-gauge engine, is about 1000 pounds. The fastening adopted in Danforth, Cooke, & Co.'s engines is somewhat similar, the principal difference being in the position of the bearing surfaces. It is shown in Plate XLVI.* In the engines by the Schenectady Locomotive Works, the smoke-box is round, and the saddle, which fits to its under side rests upon the frame, and turns down a vertical flange about 6 inches high, on each side. The cylinders are fastened to these flanges, and through a curved flange or apron to the smoke-box, without touching at any point upon the frame. In the engines by Baldwin & Co., and by the Lancaster Locomotive Works, the smoke-box is also round but no saddle is used, the cylinders being bolted to the frame and through a broad curved flange on each directly to the smoke-box—each flange of the cylinder covering, in some cases, one quarter of the whole cylindrical surface of the smoke-box. This plan requires considerable fitting, and involves nearly as much weight as the saddle. The round smoke-box is preferable to that with flat sides, being stronger and less expensive in construction, whilst from its smaller capacity the former probably possesses an advantage in respect of draught.

It is very unusual to fasten the cylinders to the framing only, excepting in the inside cylinder engines, formerly but now no longer built in the United States.

The axle-guards or pedestals, as has been stated, are usually welded, although they are sometimes bolted, to the main frame. In the deep slab frame they are forged in solid. The wearing surfaces are made upon wedges fastened in by bolts, and further confined by the flanges of the axle-boxes. These wedges, to take up the wear of the boxes, are almost indispensable in coupled engines. Their wearing surfaces are best when they are made of cast iron, as the faces of wrought-iron axle-guards are liable, unless at least 5 inches wide, to be rapidly abraded by wear. The arrangement of pedestals and boxes adopted in Mason's engines presents several good features. The legs of the pedestals are say 3½ inches wide, and are protected on each inner face by a cast-iron wedge or shoe, having flanges embracing both sides of the pedestal, and presenting a wearing face 5 inches wide. The flanges of the axle-box are extended upward so as completely to inclose the opening between it and the under side of the frame, and to support a short roller above, on which the spring, however inclined, always has a fair bearing.

In frames, the stiffness of which is dependent on so great a number of bolts, it is necessary that these should be made, as they invariably are in the best examples, to accurately fit their holes, which are carefully reamed to receive them. In Mason's engines, the various parts of the frame are planed to fit each other. It is usual, with several builders, to forge the truss bars solid with the rest of the frame, the only parts, in each truss, requiring to be fastened by bolts being the cramps across the bottoms of the pedestals.

The truck or bogie frame of the engine is usually made with inside journals only; occasionally with both inside

and outside, and very rarely with outside journals only. The principal member of the frame is a rectangular body forged from a bar 4 inches by 1¼ inch, to the under side of which wrought or cast iron knees are bolted at proper distances to form the axle-guards, these being trussed by a bar connecting their lower ends, as in the main frame. The forward end of the engine being carried usually upon the centre of the truck-frame, the cross-bars carrying the central pintle bushing are suitably trussed also. Where both inside and outside journals are applied, the under trussing bar is extended, so that its ends may bear on the outer springs, as in Danforth, Cooke, & Co's. engine, Plate XLVI.* The majority of all the locomotives now made in the United States have centre-bearing trucks, the load being carried, however, upon a broad flat circular seat from 8 to 12 inches in diameter, and only rarely upon a ball. The objection to the earlier forms of side-bearing truck, was that they would not swivel easily on striking curves, owing to the friction of the bearing surfaces, and the leverage of this friction at such a considerable distance from the centre. In Mason's engines, however, and formerly in those by the Boston Locomotive Works, the main framing of the engine rests upon each side of the truck through the intervention of a segmental roller of considerable radius, the lower end or axis of this roller being connected to the frame or directly to the springs. With this provision, the side-bearing truck swivels with great ease. The centre-bearing truck equalizes, however, the weight of the front end of the engine upon each of the truck wheels, even if one or more has sunk in depression at the joints of the rails or elsewhere. At the same time, whenever the driving wheels on one side may have sunk temporarily into such a depression, the centre-bearing truck does not fully support the engine in level, and thus there is a tendency to rolling. With the side-bearing truck, however, the distribution of weight upon the truck wheels would be disturbed whenever one sunk below the others. The centre-bearing arrangement is preferred upon the whole, and in tenders also with a truck frame under each end, that next the engine is usually made centre bearing. In the passenger and freight cars, the trucks have almost always outside journals, and invariably carry their load upon their sides.

In Bissell's truck, which has been introduced upon several lines, swivelling takes place around a joint situated several feet behind the smoke box. The truck frame carries its load near its centre, and has the usual pintle by which it is driven forward with the engine. The hinder portion of the frame of the truck is connected by two horizontal radial links with a swivelling joint just forward of the main driving axle. When the engine is running along a straight line, the form of the seats, upon which the weight is borne, holds the truck steadily; but on entering a curve it slides laterally upon short inclined planes in the seats just referred to, the axles thereby adjusting themselves in directions respectively radial or nearly so to the curve; whereas in the ordinary truck the driving axles would be forced into a position different from that which they would naturally assume in a curve. Trucks made upon Bissell's plan appear to run more steadily on straight lines and with considerably more ease in curves than the common swivelling trucks.

Cylinders, Steam-chests, and Valves.—The cylinders of American engines are always cast entirely open at both ends, the bearing surface of the covers being always outside of the counterbore. It may be remarked, that usually in English engines the hind end of the cylinder is partially covered by an internal flange, the opening being closed by a small cover, the bearing surface of which is not unfrequently made on the inside of the internal flange —the cover being passed through the cylinder from its front end. In American engines, the smoke-box is never fastened to the annular flanges at the cylinder ends, which therefore are turned on the outside to correspond with the edges of the covers, from which they are separated about ⅛ inch only. The steam-chests are never cast whole with the cylinders, but are made separately and fastened, by bolts or screw-studs, to make a ground, scraped, lead or copper joint on the upper side of the cylinder. The opening for the admission of steam is generally made in the casting of the cylinder itself, the steam entering the steam-chest (valve-box) through a rectangular port, parallel with and contiguous to the hind induction-port. In all these respects the cylinders differ from those of English engines. The flanges for fastening the cylinder to the smoke-box and frame have been already described. In one or two cases, both cylinders, for inside-cylinder engines, have been cast together. With a cylinder-face of hard iron, cast-iron valves, scraped on the wearing surface, work well, even on the variable throws of the link-motion. On the re-introduction of the link, in 1850, it was feared that the valve, by working variously with different amounts of travel, would wear the cylinder-face concavely. To guard against this supposed difficulty, a sheet of steel, with the openings for the ports properly cut through, was at one time screwed to the cylinder face, and the valve was made of hard brass. The proportions of the valves and ports differ but little from those which prevail in English engines with link-motion, and will be mentioned more particularly under the head of Valve-gear. It may be stated here, however, that in all American engines, the adjustment of the valves is such as to give a maximum admission for at least 90 per cent. of the stroke, whereas in English passenger engines the valves are not unusually arranged to cut off, whilst working at their greatest amount of travel, at two-thirds of the stroke.

The steam-chests, as has been already stated, are fastened to the cylinder by bolts, or more properly by screw-studs, tapped into the cylinder-face, and having a round collar as a head, the bearing of which is counterbored in the upper surface of the chest. These studs are prolonged, at their upper ends, to pass through the steam-chest cover, which is fastened as usual by nuts with washers underneath. In some of Baldwin's engines four bolts only are used for fastening the steam-chests, the sides of which are very deep and stiff, and the cover of which is very heavy. With the very large chests, required for the large valves of link-motion engines, as many as sixteen bolts are used for fastening the chest and cover, the bolts being rarely more than 4½ inches apart from centre to centre. Were these bolts, passing as they usually do within the chest, exposed to the steam, they would become corroded or abraded by the currents to which they would be exposed. On this account they are made to pass through suitable shields in the steam-chest casting, as shown in plan in Plate XLVII.*

In the case of engines having separate expansion valves —very few of which, however, are now made in America —these are worked either directly upon the back of the main valve, or upon a plate with ports, forming a partition across the steam-chest. When working on the back of the main valve, the suppression is more nearly instantaneous and at a less distance from the piston. The wear between the working-faces, as also upon that of the cylinder, is often aggravated, however, by this arrangement, especially with cast-iron valves. In the engines by the Cuyahoga Company, the main valves have brass faces, the metal of which is very hard, and upon which the iron backs are cast. To facilitate the grinding of the joints, the steam-chests were formerly made circular by some builders, the fastening to the cylinder being the same as has been described for the ordinary chests. So, also, the separate expansion valve was for a long time placed in a separate chest in the engines made at the Boston Locomotive Works. The cylinders and steam-chests are in nearly all cases entirely covered with Russia iron or bright brass. The latter material is not only highly ornamental, but it radiates very little heat, and the labour of keeping it clean is much less than might be imagined.

Pistons and Packing.—The form of piston usual in American engines, consists of a cast-iron body with a cover or follower fastened by four or five screw-bolts, and having two brass* packing rings cut open, each at one point only, and set out by four or five small springs, adjustable by set screws. The brass rings are either lined around their circumference, or are else plugged with Babbitt metal. They are cut open diagonally, and a ring of cast or wrought iron, ½ inch thick and cut open at one point only, is placed within them to receive and communicate the pressure of the springs, and to exclude steam from the body of the piston. The only example of the English wedge packing rings existing, as far as the knowledge of the author goes, in the United States, is in an engine built by Mr. T. B. Quigley for the Bellefontaine and Indiana Railroad. Corliss and Nightingale, of Providence, R. I., applied, in a few cases in locomotives, and very generally in their stationary engines, a form of piston in which the inner expanding ring was first made as a stout cast-iron hoop, which was afterwards cut by alternate slots on the outside and inside, so that the remaining portion had a zigzag direction throughout its course, it being finally cut open and expanded by a single wedge at one point. This form of expanding piston ring has recently been patented by Bates, York, & Parkin, of Sheffield, England. In a few cases, wrought-iron locomotive pistons have been made of the common form, the advantage being a saving of disturbing weight. Cast-iron packing rings, even when lined with Babbitt's metal, have been almost invariably found to cut the bore of the cylinder. Self-adjusting packing rings have, it is believed, never been attempted in American engines, the nearest approach being an arrangement whereby the rings are expanded by means of a conical central bolt, tightened through a small opening in the cylinder cover.

The packing of the piston-rod is rarely other than hemp, although wherever used a metallic packing has been found to answer an excellent purpose. In the bottom of the stuffing-box is placed a loose metallic ring, surrounding but not touching the piston-rod. This ring is bored out conically, so as to have a considerably larger opening at its outer than at its inner end. Three or more composition rings, each cut open at one point, and fitting closely around the piston-rod, are placed one above the other within the ring just described, to the conical bore of which the packing rings are of course turned. As the gland or follower of the stuffing-box is screwed up, these rings are tightened around the rod. The outer ring does not quite fill the bore of the stuffing-box, and the gland is bored out somewhat larger than the piston-rod, so that the rings, which are ground steam-tight on their edges, can "go and come" with the piston-rod, whenever its own axis is not coincident with that of the cylinder. The rings are made of a composition of 9 tin to 1 of copper—proportions the reverse of those of good box-metal—and the piston-rod must be made perfectly smooth to receive them.

Guide-Bars, Cross-heads, and Connecting-rods.—The guide-bars are generally flat, four to each cross-head. They are generally of iron, and where intended to take the wear of cast-iron cross-head blocks, are not case-hardened. With brass blocks or "gibs," the bars are either case-hardened or made of steel. The bars are fastened at one end to lugs on the cylinder cover, and at the other to a suitable stand or yoke, through which the connecting-rod works. The usual width of each bar is 3 inches; at the Schenectady Locomotive Works, 4 inches is allowed for heavy engines, a width which, with blocks 16 inches long, gives 128 square inches of wearing surface on the upper, and the same on the lower guide-bars. Where no gibs are employed in the cross-head blocks, "shims" or thickness pieces of sheet-tin or copper are interposed under the ends of the guide-bars, where they are fastened to their supports. As the cross-head wears, the removal of one or more of these pieces at each end brings the guide-bars a trifle nearer together. Formerly square, round, hexagonal, and even octagonal bars, variously of wrought and cast iron, were used. In some cases, as in Winans', and also in Baldwin's earlier engines, but a single guide-bar is used for each piston-rod. In those of Baldwin's engines referred to, the single guide-bar was of cast iron, hexagonal in section, and bored out to form a pump.

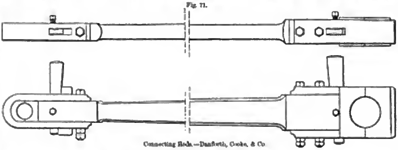
The cross-heads are almost always of cast iron, with the wrist-pin cast in. This pin is turned one half at a time, and finished by filing. The blocks, cast solid with the rest, have been for a long time successfully used in some of the best makes of engines, although when the wearing surfaces are protected by brass "gibs" the result is more satisfactory. Wrought-iron cross-heads of the form usual in English engines, were adopted in all the engines made by the Locks and Canals Company, but for the last few years they have been used only in a very few cases where it was deemed especially desirable to reduce the disturbing weight. Were it not for the small diameter of the truck-wheels, whereby the guide-bars can be placed above them, even, in most cases, with level cylinders, the double flat guides could not be used in outside-cylinder engines except by greatly extending the crank-pins, and thus widening the distance at which the power is applied

* When the term "brass" is used, excepting only where sheet brass is understood, the composition is one of copper and tin only, the best proportions being 9 of the former to 1 of the latter.

respectively to the two sides of the engine. In Mason's engines, Plate XLVII*., the axis of the cross-head blocks is placed somewhat above that of the piston-rod, the better to clear the truck-wheels.

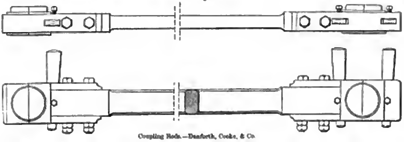
The connecting-rods of American locomotives are only rarely less than 3½ times the length of the stroke. They are in almost all cases fitted with straps, bolts, and keys at both ends. In form, they are almost always made, as in English engines, flat on their sides, their edges being rounded. In fitting the straps, the boxes, excepting the outer half at the cross-head end, have always square ends, and their flanges project on both sides to the full width of the strap. The boxes are thus held much more steadily and wear much better than where their ends are oval or octagonal and their flanges narrow. Two bolts, secured by nuts and check-nuts, are used to fasten each strap. An iron or steel plate with a raised rib on its back, receives and communicates the pressure of the key, thus giving a wide bearing on the back of the box, with a thin key—avoiding the cutting of the key, by its own pressure, into the box, and avoiding also the weakening of the strap, which would result from the use of a very thick key. The oil-cups are roomy cellars of brass or iron, fastened beneath the boxes, and communicating therewith by means of a syphon-wick. For the coupling or parallel rods, nearly the same arrangement of boxes, straps, bolts, and keys is employed. The boxes are cast to form a close cap on their outsides, to enclose the end of the crank-pin.

Fig. 71.



Connecting Rods.—Danforth, Cooke, & Co.

Fig. 72.



Coupling Rods.—Danforth, Cooke, & Co.

This cap excludes dust and adds to the appearance of the rods. It was suggested several years ago by Mr. Thomas Dougherty of Macon, Georgia, and was immediately adopted by Thomas Rogers, Esq. Various attempts have been made to connect the main connecting and parallel rods in the same line, so as to reduce the strain on the crank-pin and to diminish the disturbing weight. In one arrangement a pin was formed on the outer end of the main connecting rod strap, and to this the parallel rod was connected. This arrangement was bad, inasmuch as by the vibration of the main rod, the distance between the crank-pins of the two pairs of wheels was alternately lengthened and shortened, and what was still worse, the distance was shortened on one side of the engine, whilst it was being lengthened on the other, thereby straining the crank-pins excessively. In some engines made by Rogers, Ketchum, and Grosvenor, the strap at the forward end of the coupling rod was prolonged and fitted with boxes to receive a pin formed in a "spade-handle," at the end of the main rod. Thus the main connecting rod was attached, say 4 inches in front of the crank-pin, and although this arrangement involved an indirect strain on the bolts of the connecting rod, it worked very well in practice.

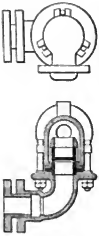
In some of Mason's engines a more elegant arrangement has been adopted. The forward crank-pin was made somewhat longer than usual, and the boxes fitted upon it were turned for about 2½ inches of their length on the pin, square thick flanges being left on the ends. The end of the main rod was forked and grasped by its straps, the square portions on the ends of the boxes, the usual keys and bolts being employed, whilst the end of the parallel rod encircled and worked upon the round part of the brasses. The end of the parallel rod had the usual strap and bolts, but only a half box of wrought-iron on one side of the brass, the inner surface of the strap working in the other.

In some of Rogers' engines the connecting rods have been first formed flat, and a semicircular groove afterwards planed out of each side, thus reducing the bar to an extremely light but stiff section. The generally great length of the connecting rods of American engines, seldom less than 7 feet between centres, makes the greatest reduction of weight important. Danforth, Cooke, & Co. have in some of their engines formed the connecting rods of $\frac{5}{16}$-inch plate iron, welded up around a forming tool, so as to make a hollow bar, the "stub ends" being suitably welded in. In Winans' engines the connecting rods are rough flat bars, the ends of the parallel rods having circular bosses upon them, with steel bushings inside to work upon the crank-pins, which are generally case-hardened, or protected with a sheet of steel welded around them to take the wear.

Pumps.—The pumps of American locomotives are now almost invariably supplied with air chambers, on both their forcing and suction sides. The fear, so often expressed, that the air in the air vessels would quickly become exhausted, appears, from experiments made with glass-vessels and also from general practice, to be altogether unfounded. With a cushion of condensed air, the

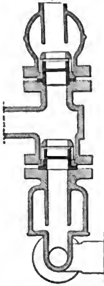
suction and delivery are very much softened, so to speak; the pump barrel "fills" without difficulty at every stroke, even with "full-stroke" pumps, which are now almost exclusively used in all engines built in the United States. The pressure within the pump, when forcing, must, at the commencement of each stroke, be considerably greater than in the boiler, inasmuch as the area of the upper sides of the delivery and check valves (clacks), upon which the boiler pressure is exerted, is considerably more than the area of their under sides, against which the pump must act to overcome that pressure. At slow speeds, the water, when forced through a glass air-vessel, rose to within about two inches of the top, each stroke of the pump being shown by a considerable pulsation on the surface of the water. At quick speeds, however, the water in the air-vessel fell three or four inches, a short column being shot up in the centre at each stroke. There could be no doubt that the absorption, by an elastic cushion of highly condensed air, of the shocks thus generated was the means of greatly relieving the pipes, valves, and joints, as well as of insuring a steadier supply to the boiler. The effect of an air chamber on the suction side of the pump, that is to say, just below the inlet valve, is hardly less advantageous. Besides relieving the feed pipe, it insures

Fig. 72.



Check Chamber and Valve.

Fig. 73.



Air Chambers and Valves.

the greatest practicable admission of water to the pump, which, otherwise, might not, even with the widest opening of the feed cocks, draw sufficient water. The first use of a suction chamber on a locomotive pump is believed to have been made by Mr. Walter M'Queen, now of the Schenectady Locomotive Works, in 1845. He applied it to an engine which he was then rebuilding for the Utica and Schenectady Railroad, and used for the vessel a piece of one of the old "De Witt Clinton's" 4-inch copper tubes. Although the air-vessels are generally made, for the sake of their appearance, of brass or copper, cast-iron, which is less porous, appears to answer the purpose in a better manner.

As has been stated, pumps working at the full stroke of the piston are almost exclusively preferred, it being understood that it is the air-vessels alone which enable such pumps to work as successfully as short throw pumps of the old kind, and such as are yet used on English engines. The arrangement of the full-stroke pumps, air-vessels, &c., will be seen in Plates XLVI*. and XLVII*. The barrel of the pump is generally of brass, the plunger a solid bar of wrought iron. The valves are generally of the cup form, as in Fig. 73. The rise of the valves is seldom more than ¼ inch, and sometimes, whilst the rise of the inlet valve is restricted to that amount, the delivery valve rises only $\frac{3}{16}$ inch and the check valve ⅛ inch. The feed pipes are fastened to the pump by a ball joint, and never by a flat flange with bolts, as is usual in England. There is always provided also a cock on the boiler, with small branch pipes leading to each feed pipe, for the purpose of admitting steam in winter, when the pumps may be in danger of freezing. Through this cock also steam may be turned through the feed pipes into the tender, to save the steam which would otherwise be blown off in standing at stations. Feed-water heaters are not numerous, although several have been tried with various degrees of success, the waste heat in the smoke-box being relied on in some, whilst in others a portion of the exhaust steam is taken from the blast pipes. The connection of the pump with the tender is invariably by means of a flexible hose, generally of canvas and india rubber, with a coiled spring inside. The sliding tubes, with ball-joints, as usually arranged on English locomotives, are never employed on American engines for connecting the pumps with the tender. Separate steam pumps, or "donkey pumps," have been often proposed, and their use would probably be attended with considerable advantage, if a simple, compact, and durable pump could be had. Those which have been occasionally tried have not been approved of, the trouble of attendance upon them being to some extent an objection to their use.

Wheels, Springs, &c.—The driving wheels of American engines are made generally of cast-iron, with 14 or 16 arms, although the driving wheels, of from 3½ to 4½ feet in diameter, for goods-engines, are sometimes of the plate or disc form, such as that adopted for the truck or carrying wheels. Considerable care is requisite to prevent the wheel casting from being strained in cooling. The various forms of driving wheels, and the precautions observed in casting, have been already described under the head of "Materials." Beyond these details of manufacture, there are few structural peculiarities worthy of note. It is satisfactory to know that wrought-iron wheels of diminished weight are being gradually substituted in place of cast-iron driving wheels, on American engines. Although the cost of the former is very much greater than that of the latter, the reduction of rigid rolling weight, greater elasticity, and the greater security of wrought iron against breaking, especially in very cold weather, render it the preferable material of the two.

With imperfect fitting, the wheels were formerly bored out with a tapering hole, the end of the axle being turned to correspond. The wheel was driven on with hammers, and after being keyed, an ornamental brass plate was screwed on the outside. The wheel would often work loose before it could be discovered that anything was

wrong. It is now becoming usual to bore the wheel with a cylindrical hole, sometimes forcing it on the axle by hydraulic pressure graduated to sixty tons, and to leave the end of the axle, turned to a neat finish, flush with or projecting slightly beyond the face of the hub. The holes for the crank-pins must of course be bored, so that they will have in both pairs of wheels the same, and properly a right, angle with each other. This is variously effected, but in several locomotive factories and railway repair shops, a "quartering machine," so called, is employed for the purpose. This is a boring lathe with double headstocks, the sides of each of which are inclined at an angle of 45° from the vertical axis of the machine. Upon the front side of one head-stock, and on the back side of the other, a boring spindle is fixed at any required distance from the centres, and the driving wheels, already fastened upon the axle, being put in place, are quickly and accurately bored. The crank-pin holes are generally counterbored to a depth of ¾ or ½ an inch, into which a collar, on the crank-pin, is sunk, thereby materially increasing the security of its fastening.

The great amount of unsuspended or non-elastic weight, where cast-iron driving wheels are used, and the rough rigid condition of the permanent way in the winter months, compels the use of very thick tyres. Very few are put on of less thickness than 2¼ inches; 2½ inches is more common, a thickness of 3 inches is not unusual, and on the New York and Erie Railway, with engines having 5 tons (of 2240 lbs.) on a wheel (and this is an unusually heavy proportion for an American engine), the tyres are more lately made 3½ inches thick. In the latter case, the tyres stretch, become loose, and require renewal when they are worn to 2 inches in thickness. The great use of sand has its influence also in wearing out tyres. It was for a long time customary to make the tyres of the front pair of coupled driving wheels (where, of course, there was a truck forward) without flanges, but more recently it has been found that, with flanges on all the tyres, their equality of diameter is better preserved, the engine runs more steadily, and the adhesion is apparently somewhat greater. At the same time, curves of from 600 to 1000 feet radius can be traversed as before.

In the springs there is little perhaps that is peculiar. The mode of spring suspension is shown very clearly in the several plates of American engines. The scroll ends, so usual in the springs of English engines, are rarely met with, it being much cheaper to form a flat seat at each end of the spring, over which a looped strap or hanger is passed and connected in the ordinary manner to the frame below. At that end of the spring which is connected to the equalizing beam, a slot is now very commonly made through the plates, a flat bolt being passed through and fastened by a transverse key above. This must, of course, weaken the spring to some extent. Screw bolts and nuts in any part of the spring-hangings are avoided, as being liable to break or jar loose.

The "skeleton spring," wherein short thin plates are interposed between the principal leaves, is more or less used. Very little of the steel used in American engine springs is more than ⅜ inch thick, much is 5/16 inch only, and occasionally ¼ inch plates are used throughout, excepting for the back plate only. In order still further to increase the elasticity of the spring-hanging, it is becoming somewhat customary to interpose blocks of india-rubber between the frame and the straps holding the outer ends of the springs, and occasionally, although not often, the equalizing lever is itself a large spring. Occasionally also, in engines with very large driving wheels and wide fireboxes, the springs, in order to be got out of the way, were placed either under the axles (as they are sometimes, but not often, arranged in English engines), or else mounted high upon the upper sides of the firebox. Either arrangement is very objectionable, as inviting lateral rolling or the failure of the pintles, by which the springs take their bearing on the boxes.

Mention has been made of india-rubber and volute steel springs, neither of which, however, are ever used for locomotives, and very rarely for tenders—their use being confined to the cars.

No draw-spring is ever applied between the engine and tender, and only in a very few instances is a draw-spring fixed on the hind end of the tender. The engine and tender are close-coupled, and a cast-iron wedge is drawn by a screw upon a tapering plate, on the back beam of the engine frame, and against the front beam of the tender, so as to prevent slack.

Valve Gear.—The link-motion has been adopted in the practice of nearly all American locomotive makers. With the exception of its use in Mr. James' engine, as already mentioned, the link was not applied in the United States until in 1847, when Mr. H. W. Farley introduced it, in the suspended form, in an engine, the "Courier," which he was at that time building for the Eastern Railroad. In 1850, Mr. Thomas Rogers adopted the suspended link in the "Atlantic" and "Pacific" engines for the Hudson River Railroad. The shifting link soon followed. William Norris had, it is true, applied links to engines which he sent abroad in 1842, but these were employed for reversing only, and not for expansive working.

With the exception of engines having lap-valves of fixed throw and adjusted to cut off at one-half or two-thirds stroke—an arrangement with which it was difficult to start a train—the separate expansion valve, working either directly upon the back of the main valve, or else upon a double ported partition across the steam-chest, was generally preferred prior to about 1853; nor was the separate valve entirely abandoned, in building new engines, until 1856. The separate cut-off valve was patented by Long and Norris, December 30th, 1833. With this valve, which could be readily thrown in and out of gear, the usual point of suppression was at half stroke, the main valve having also a slight lap, say ¼ inch at each end. In March, 1850, Mr. Ethan Rogers, of the Cuyahoga Works, Cleveland, Ohio, completed an engine in which the cut-off valve was worked with an adjustable throw from a curved rocker-arm, and within a few weeks of the same time Mr. Horace Gray, of Boston, introduced a similar arrangement upon one of the engines working on the Fitchburg Railroad. The "independent variable cut-off" soon became very popular; and with it a minimum admission of less than 12½ per cent. of the stroke has sometimes sufficed for fast trains. It was in the form in which the separate cut-off had been first applied by Mr. Ethan Rogers, that it held out so long and, for the time, successfully, against the link-motion then being introduced and improved by Mr. Thomas Rogers. The latter gentleman,

indeed, at the instance of Mr. C. C. Dennis, superintendent of the Buffalo and Erie Railroad, constructed for that line two powerful express engines, wherein the main valves were worked by the link-motion in its best form, whilst there were also separate cut-off valves capable of suppressing the steam at any desired point of the stroke. It was the intention, by working alternately with the link-motion and the independent cut-off, to determine which of the two arrangements was most economical in respect of fuel. The author is not aware that any very accurate experiments were made, but the engines subsequently made for the same line had the link-motion only.

In nearly all American locomotives, the steam-chests are on the upper sides of the cylinders, and the motion of the eccentrics is communicated to the valves through the intervention of rocker-shafts. The shifting link, or that which is made to rise or fall in reversing, is generally employed to the exclusion of the stationary or suspended link. The maximum admission of steam is generally 90 per cent. of full stroke. The earliest point of suppression or minimum admission is about 35 per cent. To this end the valve has generally a maximum throw of 4¾ to 5 inches, with from ⅝ to ¾ inch lap at each end. The steam-ports for 15-inch cylinders, are rarely less than 14 inches long, and Messrs. Niles & Co., of Cincinnati, Ohio, have made 18½-inch ports for that diameter of cylinder. The width of ports varies from ⅞ inch to 1⅛ inch for induction, and from 2 inches to 3½ inches for exhaust. It was formerly customary to give ⅛ inch inside lap at each end of the valve, even for express engines. In some of Rogers, Ketchum, and Grosvenor's engines with but ⅛ inch inside lap on each side, the exhaust was delayed, when cutting off at 36 per cent. of the stroke, to 17¾ inches of a 22-inch stroke, but on the return stroke, the exhaust was interrupted and compression commenced at 13½ inches, or at 61 per cent. of the stroke. Better results, it is thought, are now attained by cutting out the throat of the valve to the full width between the inner edges of the steam-ports, and even, in some cases, by giving a slight inside clearance.

The suspension of the link is determined respectively by each builder from trials made upon such proportions as he may have adopted. Hence with some links the point of suspension is at the centre of the link both vertically and horizontally, in others, as in Mason's engines, 2½ inches above the centre, and, in others still, at various distances in front or behind the centre. So, too, the radius of the centre of the link, which is in some cases exactly equal to the distance from the centre of the eccentric to the centre of the link, is in others, as in the engines by the Taunton Locomotive Manufacturing Company, 2 inches more, and again, as in the engines by the Rogers Locomotive and Machine Works, 6½ inches less than that distance.

As regards the mechanism of the link-motion, as applied to American engines, the whole link is generally of wrought iron, formed in a single piece and case-hardened. The knuckle-joints, or points of connection of the eccentric rods are generally on the back side, and rarely at the ends of the link. Several builders, however, form the two sides of each link in separate pieces, bolted together through distance-pieces at the ends. Occasionally, as in several engines built by Mr. Seth Wilmarth, of Boston, the link is a solid curved bar, grasped by a box to which the valve-rod is attached. Cast-iron links have been occasionally used, and they have been found to wear very well. In the best class of workmanship, the holes through the link, where the knuckle-joints are made, are bushed with steel, and the bolts through the ends of the eccentric-rods have steel thimbles. The links are still counterweighted, by some makers, with weights, but either a coiled, a volute, or an ordinary plate spring, is generally preferred, the spring being sometimes placed upon the footboard as in Mason's engines, and in other instances near the tumbling-shaft.

The distribution of steam, with the link-motion, cannot be considered as altogether satisfactory, and the American builders had substantial grounds for the opposition which they made against its introduction. Whatever may be the actual consequences of compression, there is evidence that, with the link, the steam is "wire-drawn" to an injurious extent, or to such an extent that the point of suppression must be delayed, and a portion of the advantage of expansion sacrificed, owing to the reduced pressure at which the steam enters the cylinder. When cutting off at three-eighths of the stroke, there are few American engines, with link-motion, wherein the steam-port is opened to a greater width than ¾ inch. With a 17-inch cylinder, 20-inch stroke and 6-feet wheel, going a mile a minute, the distance made by the piston in that time is 934 feet. With ports 14 inches long, an opening of ¾ inch, when cutting off at three-fourths of the stroke, requires a velocity of ingress of the steam of 18,298 feet per minute to preserve upon the piston the full pressure of steam in the chest. But with an opening of only ¾ inch, when cutting off at three-eighths stroke, the velocity of entrance of the steam must be hastened to 39,982 feet, or 7½ miles per minute, equal to 43 times the speed of the piston, in order to prevent wire-drawing. When cutting-off at three-eighths stroke, and opening the port for but ¾ inch, the throw of the valve is only 2¼ inches; hence its motion is comparatively very slow, especially just as the port is being opened. Mr. G. H. Corliss, now of the Corliss Steam-engine Company, of Providence, R. I., applied to a locomotive, the "Advance," which he commenced in 1853, a form of valve-gear by which the distribution of steam was improved, at the expense, however, of considerable mechanical complication. There was a separate induction and eduction valves and ports at each end of each cylinder, the ports being as short and opening as directly as possible into the bore. The valves worked with a vibratory motion, each within a cylindrical chamber, instead of sliding upon a flat surface. The motion from the eccentrics was first communicated from each to a "wrist-plate," a circular disk vibrating around its own centre, and having four pins on its outer face, each pin being connected to an arm working one of the valves upon one cylinder. The pins on the "wrist-plate" were so situated, that whilst the induction valves were opening and closing, both the eccentrics and the pins (which were of course equivalent to cranks) were at half-throw, or at their points of most rapid motion. And thus when the valves were entirely opened or closed there was a comparative pause, the effect being to throw the port almost instantly open, and to keep it open until the time arrived for almost instantly closing it. The motion was somewhat similar to what

would be adopted with a cone, but the uniform and easy action of the eccentric was retained.

Mr. Corliss' engine, as compared by the indicator with a link-motion engine, both moving at the rate of about ten miles an hour, showed the following results. In cutting off at half-stroke, with a boiler pressure of 85 lbs. per square inch in both engines, the cylinder pressure at the commencement of the stroke was in the Corliss engine 84 lbs., and in the link-engine 72 lbs. The average pressure throughout the stroke was in the former 63½ lbs. against 49½ lbs. in the latter. The highest pressure of compression was, in the link-engine, 35 lbs.; in the Corliss engine, 9 lbs.; and the average back pressure was 3¾ lbs. in the former, against ½ lb. in the latter. In cutting off at 16 inches, 14 inches, 12 inches, 8 inches, and 6 inches respectively of a 20-inch stroke, the comparative superiority of the Corliss valve-gear was much the same. The stationary engines made by the Corliss Steam-engine Company have a similar valve-gear, and are celebrated throughout the United States for their light consumption of fuel, often less than 2½ lbs. of coal per horse power per hour. For locomotives, however, the arrangement was exceedingly complicated, although it was due less perhaps to this reason, than to various other difficulties, that the valve-gear of the "Advance" has never been reproduced in any locomotive since built by the same makers.

The New Jersey Locomotive and Machine Company have applied, to several of their engines, an arrangement of valve-gear devised by Mr. H. Uhry, the manager of the works, and Mr. H. A. Luttgens, also of Paterson, N. J. This is a modification of the ordinary shifting link-motion. The eccentrics, links, valves, and connections are generally the same, and are placed the same, as usual; but the block, on which the link works, instead of being attached to the lower end of the ordinary rocker-arm, is carried on the upper end of an arm, attached to, and vibrating upon the lower end of the rocker-arm; whilst the lower end of this supplementary arm receives motion, through a suitable connection, from a triangular cam placed upon the driving-axle. The motion of the valve thus partakes of that of the eccentrics, acting through the upper end of the supplementary arm, and of the motion of the cam, acting, as already stated, through the lower end of that arm. The effect is to open and close the valve more suddenly than in the ordinary manner, as also to open the ports, when cutting off early, to a greater width, and, by delaying the closing of the exhaust-port, to diminish compression. The results, therefore, must be similar in kind to, although perhaps different in degree from, those attained with the Corliss valve-gear; as compared with which it is, however, much less complicated, besides being readily applicable to existing engines. The results reported of the Uhry and Luttgens valve-gear are very favourable.

Mr. Richard Colburn, of the Norwich and Worcester Railroad, and Genl. Henry Bates, have both introduced small supplementary valves designed to release the steam compressed in the cylinder after the closing of the exhaust-port. In the indicator diagrams, taken at high speeds, and at the shortest throws of the valve, compression was entirely obviated, but there is much difference of opinion as to the real influence exerted by compression upon the power of the engine, and hence the valves under notice have not been adopted to any considerable extent.

In Winans' engines, as has been already stated, the valves are worked either at full stroke by eccentrics, or at half-stroke by an abrupt cam-motion.

Some attention has been directed to relieving the friction due to the pressure of the steam on the valves. Mr. Wilson Eddy, in building an engine, some nine years ago, for the Western Railroad of Massachusetts, made the valves work, steam-tight, upon their backs as well as their faces. On the Boston and Worcester and Fitchburg Railroads, a piston-valve, of a form patented by Mr. Joseph Marks, was at one time tried, and, as was then believed, with considerable success. The steam-chest is a cylinder, of a bore of from one-half to two-thirds that of the main cylinder, and has short straight steam-ports opening into the ends of the latter. Two pistons, with solid packing-rings, answer to the working faces of the common valve. The working of the piston-valve is not only easy, as long as it is in good order, but the exhaust, by being first released into the space between the pistons, is equalized and converted into a nearly continuous draught upon the fire. The arrangement is faulty, however, from the difficulty of properly maintaining the packing. A form of balanced valve similar to that adopted by Mr. Daniel Gooch on the Great Western Railway (of England) has been introduced also by Mr. Henry Waterman, but the author is unable to supply any definite particulars of the results. Several years ago, Mr. Thomas Rogers applied valves, called V-valves, to some very heavy express engines made by him for the New York and Harlem Railroad. The valve-faces of the cylinder presented two inclined planes opposite each other, like the inner sides of the letter V, and upon each face was a valve, the two being connected by a link, so that the pressure upon each valve tended to lighten that of the other upon its own seat. The cylinders were subsequently replaced by others having the ordinary flat valve-seats.

Efforts are being, and will continue to be, made in the United States to secure, with the variable suppression afforded by the link-motion, a full and nearly instantaneous opening of the steam-port, holding it open until the proper point of cut-off has been reached, when the valve would be closed with equal rapidity. With this provision, requiring possibly separate induction and eduction valves, the steam would enter the cylinder at the highest possible pressure, whereby the greatest degree of expansive working might be attained. With such an arrangement, the valves being also balanced and the cylinders steam-jacketted, or the steam else superheated, it is believed that a very high degree of economy would be realized.

General Details.—The boilers of American locomotives are covered with pine lagging, or cleading, over which is a covering of planished Russia sheet-iron, confined by broad brass bands, the latter always polished and often richly moulded. Over the foot-plate is erected a handsome "cab," having a curved roof at a clear height of at least 6 feet 6 inches. The frame of this house is strongly made, and it is glazed both in front and at the sides, the front windows being made to open, to allow the fireman to go out to oil the cylinders, whilst the side lights are also made to slide. Seats for the engineman and fireman are always provided, and the latter generally supply themselves with cushions. In cold weather, canvas curtains are often put up next the tender, so that the men are com-

pletely inclosed. The "cab" is often of a very elegant architectural design, and in its external finish the choicest varieties of wood are frequently used, whilst in common with the rest of the engine it is handsomely painted and often superbly decorated. The ornamental character of American engines is indeed remarkable. Besides the profusion of heavily moulded and highly polished brass in the cylinder and steam-chest covers, on the domes, the boiler-bands, whistle-stand, air-vessels, name and number-plates, &c., all the unfinished work is painted in showy colours, and the most ambitious efforts of decorative art are occasionally exhibited upon the panels along the sides of the tenders. The "head-light" or lantern is a prominent feature of American locomotives. It is generally erected upon the front of the chimney, and the parabolic reflector, heavily plated with silver, is seldom if ever less than 18 inches in diameter—more often 21 or 22 inches, and in many cases 15 inches deep. Oil is usually burned in the lamps of these lanterns, but sometimes gas, distilled from "burning fluid," is used with an improvement in the brilliancy of the light. The rays being concentrated and thrown directly along the line, enables the engineman, in dark nights, to distinguish large objects, like cattle, at 1000 feet a head of the engine. These lamps cost from £15 to £25 each. The whistles are seldom less than 4½ inches diameter, with a bowl 6 inches high, but they are generally still larger, and their sound is extremely deep and powerful. Steam is let on to them, in every case, through a spring-valve, fitting to a conical seat; the simple turn-cock, as in English engines, never being employed for that purpose. In addition, there is always a bell, seldom of less than 60 lbs. weight, and in some cases as heavy as 215 lbs., mounted in an ornamental stand on the top of the boiler. The bell is always rung at a quarter of a mile from every level crossing, the ringing being continued until the crossing is passed. The whistle is used chiefly for signalling the departure of the train from stations, and its approach to terminal stations, as also for putting on the brakes in cases of danger. In a few cases, the whistle is blown at crossings, by an automatic apparatus, connected with the truck-wheels of the engine. As a certain number of revolutions of these wheels represent a certain distance gone over, their motion may be communicated by a train of screw-worms and gearing to a slowly revolving drum on which are stops corresponding with the points along the line at which the whistle requires to be blown. This arrangement has been adopted in a few instances with satisfactory results, the whistle being blown at every crossing without attention from the engineman. There are simple provisions for correcting the deviations due to the gradual wearing and consequently increasing number of revolutions of the wheels in running a given distance. In a few cases, also, a few octaves of steam-whistles have been set up in a frame and blown with low-pressure steam; very good and certainly very powerful music being discoursed, either by manual operation on keys, or by a revolving barrel with studs. This arrangement, known as the "Calliope," has not, however, been applied to locomotives, but it has been successfully tested on a number of steamboats, to the great admiration of the passengers, and of the public within hearing.

Almost every engine is provided with a sand-box of an ornamental design, and mounted upon the boiler. Bourdon's pressure-gauge is commonly employed, and in addition to from three to seven water-gauge cocks (the author knows of instances in which the latter number is used), there is often a water-gauge acting upon some modification of the float principle. Glass tubes, however, are only very rarely employed.

With but one or two exceptions, the trains, upon double-track railways in America, run upon the right-hand line, instead of on the left, as in England. The levers and the post of the engineer are in the former case, as in the latter, upon the right-hand side of the engine, thus bringing the American engineman to the outside of the double line. Upon the Boston and Lowell Railroad, however, the engineman's post is or was on the left-hand side of the engine, so that, when running on the right-hand line of the double track, the view was directed between the two lines of rails.

No American engine would be complete without a "cow-catcher" or pilot, the construction of which formidable appendage is clearly shown in the several plates of American engines. Cattle being allowed occasionally to stray upon the line, are cleared without ceremony by the "cow-catcher," and the more effectually, as doubtless with more safety to the train, when its speed is above 30 miles an hour. Upon some of the Western railways, the horizontal length of the "cow-catcher," when made of wood, is 6 feet, and as it is only 2½ inches clear of the rails, it is very heavily braced. The weight of this structure often exceeds 1000 lbs. In heavy snows, a plough of large size is fitted in front of the engine, to clear the line. These ploughs were formerly made on separate carriages, heavily loaded and pushed by the engine, but it is now preferred to fasten them directly to the engine itself.

Within the "cab," and within a few inches of the engineman's head, is a large gong or flat bell. A spring hammer is so adjusted as to strike this gong by pulling a trigger, to which is attached a small but strong cord, extending back throughout the train. Each car carries its own length of cord, the connection of the whole being made by spring hooks or "snaps," which can be coupled or disengaged in a moment. The signal-cord runs within the reach of every passenger in the train, and when the latter is in motion, a stroke upon the gong is a signal for immediately stopping the engine. Nothing could exceed the simplicity and efficiency of this mode of communication, whilst instances of its wilful abuse by mischievous persons are almost unknown.

The tenders are constructed to carry from 1200 to 2000 gallons of water, and from 1 to 3 cords (128 to 384 cubic feet) of wood. They are generally mounted upon two truck-frames, one under each end. The forward truck is generally made to carry its load upon its centre, being similar in construction to the engine-truck. The hind truck carries its load on its sides, the whole weight of the tender being thus supported in three points. Not only is the tender provided with powerful brakes, but brakes are usually applied, excepting upon the railways in the Southern States, to every wheel in the train. Various automatic brakes have been devised, some of which are in considerable use. A moderate number of tank-engines have been built, and with the further improvement of the locomotive, so as to diminish the quantity of fuel and water required to be carried, the separate tender will doubtless be dismissed in a great number of cases.

COAL-BURNING LOCOMOTIVES.

THE coals burned in American locomotives are of the anthracite, bituminous, and semi-bituminous varieties. The former contains but a small percentage of hydrogen, and burns without smoke. The bituminous coal burns generally with much smoke, and both kinds are apt to contain a considerable quantity of fusible matter forming clinker. The semi-bituminous variety, better known as Cumberland coal, has many characteristics in common with Welsh coal.

One of the earliest engines built in the United States, that made in 1831 by Phineas Davis for the Baltimore and Ohio Railroad, burned anthracite coal, notwithstanding that the line of railway was to extend into the Cumberland coal region, where a fuel every way better was to be had. In 1836, anthracite coal was adopted successfully in the engines of the Beaver Meadow Railroad, a line extending into an anthracite coal district. As far as anthracite coal is concerned, the experience of several important lines of railway has shown that there is no mechanical difficulty in burning it; this coal is placed in engines very similar in their construction to those burning wood, and an abundance of steam is maintained, and the injury to the boiler, with iron fireboxes, iron tubes, and wide water-spaces, is not excessive. But as far as experiments have been made, not more than from 5½ to 6 lbs. of water seem to be evaporated for each pound of anthracite coal so burned, whereas this variety of fuel should vaporize from 8 to 9 lbs. of water for each pound of its own weight. It may be added that, notwithstanding that the quantity of anthracite coal raised in the United States, is more than three times greater than that of all other varieties, the former, all of which comes from a comparatively small district, is never burned in locomotives excepting in those running within the immediate region of its own production; whereas the bituminous and semi-bituminous coals, the deposits of which underlie more than 150,000 square miles of the area of the United States, are selected wherever coal is burned in locomotives out of the anthracite district.

Smoke-producing coals are burned, in the United States, in a great variety of locomotive boilers. Upon the Baltimore and Ohio Railroad, an excellent coal is very imperfectly burned in the Winans' engines with which that line is chiefly provided. The fireboxes have grates 7 feet long by 3 feet 6 inches wide, for 19-inch cylinders, 22-inch stroke, and eight 43-inch coupled driving wheels. The grate-bars, of which there are but twelve, have 1¼-inch openings, and the iron tubes, which are nearly 14 feet long, are 2¼ inches in diameter. There is hardly any special provision for the combustion of the gaseous portion of the coal; and not only is much smoke produced, but the evaporation is necessarily very much diminished in consequence. It is indicative of what seems to have been a general want of a proper knowledge of the principles of combustion, that the majority of coal-burning locomotive-boilers, until very recently brought out in America, have been contrived upon an entirely mechanical view of the problem to be solved. It is not necessary to enter here upon the chemical consideration of combustion, further than to observe that no combustible can be burned without complete combination with atmospheric oxygen. Whilst solid carbon, as coke or charcoal, may lie still upon a grate, awaiting the access of air, and will decompose and burn no faster than the air may arrive to its incandescent surfaces, the gaseous portions of raw coal are distilled at a moderate heat, and, unless instantly saturated with air, escape in a rapid flight, not only unconsumed, but, whilst thus unmixed with air, in a condition in which ignition is absolutely impossible. It is a matter of the readiest proof, not only that the volatile portions of bituminous coal are the only portions of that substance from which smoke can be produced, but that these portions contain about one-third of its ultimate heating power. Without air these volatile matters are as incombustible as air itself, combustion being indeed chemical combination only, in which the gas and air are burned alike, the process of combustion being in every respect mutual. Until recently, no American coal-burning boiler has been arranged with reference to the interfluence of the coal-gas and air, and, as a necessary consequence, with flame-producing coals, much smoke was made, and the heating power of the coal was often inadequate to the work demanded of the engine. To show the importance of the adaptation of coal as a fuel on American railways, it may be stated that the cost of wood-fuel is, in many cases, as great as 25 cents (12½d.) per train-mile run. Upon one railway in Massachusetts, the average cost per train-mile was, for 1857, 31 cents (15½d.)

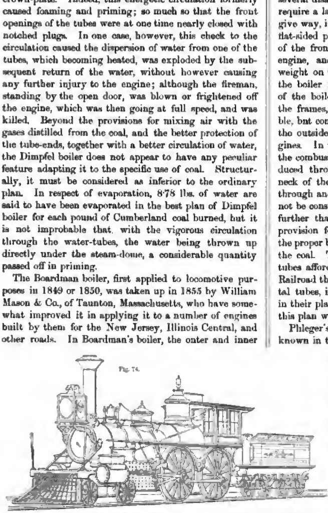
On the first introduction of coal into engines of nearly the ordinary construction, it was found more or less difficult to maintain the requisite pressure of steam. The fire could not be kept uniformly active. The American coals contain a large proportion of fusible matters forming clinker, and which, by melting and closing the interstices of the grate-bars, greatly impeded the draught. Again, the heavy firing going on at intervals, periodically diminished the production of steam, a great quantity of heat being absorbed in the volatilization of the gases from the fresh coal. Towards the correction of these evils, the furnace was lengthened and the grates raised so as to leave less room between the surface of the fire and the crown-plate. The grate-bars were, in nearly all cases, made so that they could be rocked or agitated whilst the engine was running, the object being to loosen the vitrified clinker. A variable exhaust was provided in the chimney, so as to admit of regulating the fire. Beyond these provisions, arrangements were occasionally introduced for "burning the smoke," on the supposition that, without reference to any admixture of air, the smoke-producing gas was by itself combustible, provided only that it were passed over incandescent fuel.

Among the earliest plans of coal-burning boilers, that of Monsieur Dimpfel, formerly of Besançon, France, now of Philadelphia, U.S., merits attention. In Dimpfel's boiler, the external appearance of the ordinary wood-burning construction is preserved. The inner fire-box, however, is extended, in the form of a long combustion chamber, nearly to the front end of the barrel of the boiler. The tubes are made to contain water, and are surrounded by the fire. They descend from the under side of the firebox crown-plate, and, bending by an easy curve to a right angle, extend to a water and steam chamber at the front end of the boiler. Within two or three years this form of boiler has been improved in some of its details, and re-introduced by the Taunton Locomotive Manufacturing Company. The flat roof of the combustion-

chamber and the concave crown-plate (serving also as the tube-plate), were strongly stayed from the outer shell of the boiler; an air-pipe, opening near the front end, received and distributed air throughout the length of the combustion-chamber, whilst hollow stay-bolts on the back side of the firebox and air openings in the door-plate, all under the control of dampers or regulators, admitted a further supply. The furnace was of good length, and in several instances, with large express engines burning Cumberland coal, abundance of steam was kept up with very little smoke. The circulation of water through the tubes is such, that a half-pound bolt has been drawn through the length of a single tube and thrown upon the crown-plate. Indeed, this energetic circulation formerly caused foaming and priming; so much so that the front openings of the tubes were at one time nearly closed with notched plugs. In one case, however, this check to the circulation caused the dispersion of water from one of the tubes, which becoming heated, was exploded by the subsequent return of the water, without however causing any further injury to the engine; although the fireman, standing by the open door, was blown or frightened off the engine, which was then going at full speed, and was killed. Beyond the provisions for mixing air with the gases distilled from the coal, and the better protection of the tube-ends, together with a better circulation of water, the Dimpfel boiler does not appear to have any peculiar feature adapting it to the specific use of coal. Structurally, it must be considered as inferior to the ordinary plan. In respect of evaporation, 8·78 lbs. of water are said to have been evaporated in the best plan of Dimpfel boiler for each pound of Cumberland coal burned, but it is not improbable that, with the vigorous circulation through the water-tubes, the water being thrown up directly under the steam-dome, a considerable quantity passed off in priming.

The Boardman boiler, first applied to locomotive purposes in 1849 or 1850, was taken up in 1855 by William Mason & Co., of Taunton, Massachusetts, who have somewhat improved it in applying it to a number of engines built by them for the New Jersey, Illinois Central, and other roads. In Boardman's boiler, the outer and inner fireboxes are of the ordinary form, but from the upper portion of the latter a long combustion-chamber, with flat top and bottom, is extended to and opens into the smoke-box. From the bottom plate of this chamber a large number of short vertical tubes descend through a tube-sheet and open into an ash-pan below. The tubes, say 379 in number, 1¾ inches in diameter, and 3 feet 8 inches long, are surrounded by water, which is inclosed by the flat sides of a large vessel depending from and united with the cylindrical, or rather semi-cylindrical portion of the boiler. A diaphragm or partition is placed across the combustion-chamber, at about 6 feet from its opening into the firebox, and so as to send the whole of the draught downwards through some 250 tubes in the hinder part of the flat-sided vessel, and into the ash-pan below. From thence the draught rises through the remaining 129 tubes and passes from the front part of the combustion-chamber into the smoke-box. Structurally, this form of boiler has several disadvantages. The flat sides of its lower portion require a large number of cross stays; and if one of these give way, it can only be renewed with great trouble. The flat-sided portion, containing the tubes, is placed in front of the front-driving axle, in the ordinary eight-wheeled engine, and by its weight considerably increases the weight on the truck-frame; indeed, the whole weight of the boiler is materially increased. So too this portion of the boiler occupies nearly the whole width between the frames, not only rendering inside cylinders impossible, but compelling also the removal of the valve-gear to the outsides of the wheels, even in outside-cylinder engines. In this form of boiler the dividing diaphragm in the combustion-chamber is made hollow, and air is introduced through it, as also through hollow stays in the neck of the combustion-chamber, and through openings through and above the door. The Boardman boiler cannot be considered as adapted specifically to the use of coal further than in that its combustion-chamber, with the provision for admitting air to above the fire, may insure the proper burning of the combustible gases given off from the coal. There is no evidence to show that the vertical tubes afford any advantages; and on the Illinois Central Railroad they have been removed, and ordinary horizontal tubes, in the common cylindrical barrel, substituted in their place. There is little probability, therefore, that this plan will be adopted further in new engines.

Fig. 74.



Coal-burning Engine, with Boardman's Boiler, built by Wm. Mason and Co., for New Jersey Railroad and Transportation Company.

Phleger's coal-burning boiler has been for a long time known in the United States, and comprises some features especially adapted to the combustion of coal; although expedients of greater simplicity are now adopted which render the ordinary wood-burning boiler equally, if not more effective for that purpose. Externally, Phleger's boiler presents the ordinary firebox and barrel, the latter however, in some of the earlier boilers, being placed very low down, and within a short distance of the rails,—out-side cylinders and valve-gear being employed. In the earlier examples of this boiler, a water-space or "water-bottom" extended across the bottom of the firebox; the grate was formed by a series of water-tubes, and the air necessary for draught was forced in under pressure. That side of the firebox in which the tube-plate is ordinarily placed, was carried up to within some 18 inches, more or less, from the crown-plate, an opening communicating thence into a combustion-chamber situated in front of the driving axle. This chamber extended downwards, in front of the axle, to within perhaps 2 feet from the rails,

and from its front side the tubes passed off through the cylindrical barrel in the ordinary manner. From the crown-plate of the firebox, also, a transverse hanging water-bridge depended in front of the opening to the combustion-chamber. The object of this arrangement was to secure room and time for the mixture of the coal-gas and air in combustion; and, as far as it went, this plan answered a very good purpose. In later engines, with the Phleger boiler, the author believes that the water-bottom and forced draught have been omitted.

In 1851, Alba F. Smith, Esq., now superintendent of the Hudson River Railroad, specified the combustion-chamber as used by J. E. M'Connell, in 1852, for some engines which were then being built for the Cumberland Valley Railroad, of which Mr. Smith was at that time superintendent. The engines were completed in the early part of the year 1852, since which time they have been running regularly, burning wood; but the combustion-chamber has since been very generally adopted in coal-burning engines. Mr. Smith applied the steam-jet in the chimney, at about the same time, and this contrivance has long since become indispensable in nearly all plans of coal-burning engines.

In the year 1852, Mr. James Millholland, locomotive-superintendent of the Reading Railroad, placed a combustion-chamber nearly in the middle of the length of an ordinary cylindrical barrel, a series of good-sized tubes, say 2½ inches diameter, communicating with the firebox, whilst another series of smaller tubes led into the smoke-box. This arrangement, known as "Millholland's boiler," had been contrived some years before in England, but Mr. Millholland had patented its "combination" with a grate, having the sides and front ends closed up solid by what is called a "dead plate." The plan was brought out for burning anthracite coal, a large firebox with movable grates, as in Winans' engines, being used. There was no evidence, however, that any additional combustion was effected in the intermediate chamber, and the hollow stay bolts originally provided through the sides of this chamber were soon after closed. Admitting the production of carbonic oxide from the burning coal, the best place for intermixing air, so as to convert this gas into carbonic acid, is clearly within the fire-place itself, if not indeed within the incandescent fuel. Mr. Millholland has abandoned this arrangement of combustion-chamber in his later engines.

In 1855, Mr. O. W. Bayley, of the Manchester Locomotive Works, brought out a novel plan of boiler for burning bituminous coal. Externally, it was of the ordinary form and proportions, but the firebox was arranged as follows:—An inclined water-space, extending from just below the lower tubes, backwards and upwards, to within a few inches of the crown-plate, completely divided the upper portion of the firebox from the lower. The lower portion was further subdivided by a longitudinal water-space or mid-feather extending along its entire length. Each lower compartment had its grate and door, and there was an opening also (which could be closed by a regulating damper) from each lower compartment into the upper chamber of the firebox. There was also a large square opening at the forward end of the longitudinal mid-feather, which last opening was kept always open. The mode of working was as follows: one of the regulating dampers, say the right-hand one, being closed, the right-hand door was opened and coal fed to the right-hand grate. The opening from that compartment to the upper chamber being closed, the products of combustion were forced to pass through the mid-feather into the adjoining compartment, and thence, over incandescent fuel, up through the left-hand damper into the upper chamber and thence away through the tubes. For firing into the left-hand compartment, this adjustment of dampers was reversed. The object in this plan was to burn the gases by direct heat, which could only be done after they had been properly saturated with air. In practice, it was found difficult to keep the water-spaces tight, and simpler means were found to be effective in burning the same kind of coal without smoke.

Towards the end of the year 1856, Mr. G. S. Griggs, of the Boston and Providence Railroad, erected an arch of fire-brick across the width of an ordinary wood-burning firebox, and at such height that the crown of the arch was just below the bottom tubes. The gas from the coal, with which the firebox was thus worked, was deflected backwards under this arch and into mixture with air entering through several hollow stays behind. There was thus considerable room, and an appreciable space of time for gaseous combustion in the upper portion of the firebox. Mr. Beattie subsequently adopted a similar arch in his coal-burning engines running on the London and South-Western Railway; and the deflectors now employed by Mr. Yarrow and Mr. Jenkins, and illustrated on page *29, are identical in principle. In the United States the simple and inexpensive firebrick arch has been extensively applied in wood-burning engines, which have thus been enabled to burn Cumberland coal with little smoke, and with a satisfactory command of steam.

Upon the Hudson River Railroad, a considerable number of wood-burning engines have been altered, as follows, for burning coal:—A combustion-chamber has been extended for from 5 to 5½ feet into the body of the boiler, a mid-feather being extended through from 2½ to 3 feet of this chamber, or to within 2½ feet of the tube-plate. Into the mouth of the chamber, and on each side of the mid-feather, a firebrick wall is built up to within 12 inches of the crown-plate. The lower plates of the firebox, for 2 feet above the grate, are of copper, the rest are of iron. There are twenty hollow stays, of 1 inch diameter of opening each, through the back side of the firebox, the air entering at about the level of the top of the burning coal, which is maintained at a depth of from 10 to 14 inches on the grate. The coal is fired at frequent intervals, a single shovel-full only being thrown on at a time, this being distributed as uniformly as possible. The grate-bars are closed solid, for one-half of their entire length, at their front ends; making a "dead-plate" of from 2 to 2½ feet in width next to the combustion-chamber. In these engines, as in those fitted with Griggs' firebrick arch, the ordinary chimney of the wood-burning engines is retained, although but a small quantity of unconsumed coal and cinders escape from the fire. The Hudson River engines have each a steam jet in the chimney, to keep down smoke when standing at stations. The grates are fixed, and are never disturbed whilst running, the coal being comparatively free from clinker. These engines, with 16-inch cylinders and 22-inch stroke, draw trains of

from 60 to 110 tons weight, exclusive of engine and tender, at from thirty to forty miles an hour over a level line, with an average expenditure of 24 lbs. of Cumberland coal per mile. Very little smoke is made, and the pressure of steam is easily maintained.

Coal-burning engines upon nearly the same arrangement have been built by the Schenectady Locomotive Works, the Lawrence Machine Shop, and by Danforth, Cooke, and Co.

The coal-burning engines made by the Rogers' Locomotive and Machine Works have a combustion-chamber, of from 3 to 4 feet in length, extending into the barrel of the boiler. A "dead-plate," made to drop on a hinge when required, is placed at the front ends of the grates, the bars of which are so arranged, that when the clinker requires to be broken and removed, they may be alternately raised and lowered, one series of the bars descending between those of the other series at the same time ascending, there being also alternate projections on the sides of the bars to assist in breaking up the bottom of the fire. Arrangements of movable grates, very much like that described, are considerably used in American coal-burning engines. In the Rogers' engines, air is admitted through numerous small openings in the door, as also through a perforated diffusing box or chamber just below the door and within the firebox. In the smoke-box the nozzles of the exhaust pipes are placed nearly on a level with the bottom row of tubes (as the exhaust nozzles in American wood-burning engines also are usually placed), and about 15 inches in front of the smoke-box tube-plate a plate-iron partition extends across the smoke-box, the outlets for the products of combustion being under the bottom and over the top of this plate, as well as in six slots of about 12 inches by 4 inches each, cut through it. The exhaust being discharged in front of this plate, the action of the draught is rendered nearly equal through all of the tubes, instead of being strongest, as it would otherwise be, in the upper row of tubes.

Various arrangements have been for a long time employed in the United States for equalizing the draught through the tubes; and with coal-burning engines, some contrivance for this purpose is considered indispensable. In any locomotive boiler with the ordinary draught, the heat rises naturally to the upper part of the furnace, whence its shortest course is through the upper tubes. If the mouths of the exhaust nozzles are at the level of the upper tubes, this unequal diffusion of heat is increased. As early, at least, as 1848, Mr. Ross Winans, in his coal-burning engines, made the exhaust nozzle at the level of the bottom row of tubes. Concentrically over the nozzle was placed a cylindrical pipe, of about 10 inches diameter, extending up to a few inches within the base of the chimney, between which and the pipe there was an annular opening of perhaps 2½ inches in width. The action of the draught was thus exercised entirely at the bottom and the top of the inner pipe, and thence, somewhat equally, upon all the tubes. In 1854, it became general, in wood-burning engines, to set up an arrangement of short pipes, one over the other, and each made in the form of a truncated cone, annular openings being left between the base of each pipe and the top of that next below. This arrangement is known as a "petticoat pipe," and the exhaust steam being discharged from below, passes up through the series, drawing in from the tubes at each opening. A similar arrangement of cylindrical pipes is shown in Plate XLVI.* In 1848, too, in burning wood and coal mixed in the engines of the Philadelphia and Columbia Railroad, it was found necessary to set up a plate-iron partition nearly across the smoke-box, between the tube-plate and exhaust pipes, in much the same manner as in the Rogers' engines. In the Columbia engines, however, the plate was not cut through at any point, but an annular opening of 3 or 4 inches width was left around it. In the engines of the Hudson River Railroad, Mr. A. F. Smith has successfully applied a novel arrangement for equalizing the draught through the tubes. Within the chimney is a pipe, which may be raised or lowered, so that its bottom may be placed at the base of the chimney, or be dropped down to half the depth of the smoke-box. This pipe is about 4½ feet long, its ends are of the internal diameter of the chimney, to which it fits, but it is contracted to say 11 inches in diameter for about 20 inches of its middle length,—forming what would be known in hydraulics as a *vena contracta*. When dropped to the lowest limit of its fall, this pipe, through which all of the draught has to pass, sensibly increases the energy of the fire, besides bringing more of the heat through the lower tubes. The sharp intermittent action of the blast was once indeed considered so prejudicial to the proper condition of the fire, that on one of the mineral railways, the exhaust steam was at one time let into a box 1 foot in diameter and 1 foot high, eighteen 1-inch tubes at the top affording exit to the steam.

Mr. W. H. Bullock, of the Old Colony Railroad, has adapted a plate-grate, or grate in which circular holes through a cast-iron bottom admits air to a coal-fire. In the smoke-box, above the mouths of the tubes, but below the exhaust nozzles, a wire-cloth screen is placed to intercept flying coal, which is led off through a spout into a box beneath, called a "sub-treasury," as the old spark-boxes also of the wood-burning engines were formerly called.

Many of the schemes described are employed only to burn Cumberland coal, which is altogether superior in quality to that found west of the Alleghany Mountains The western coal is generally very impure; it contains considerable sulphur, it disintegrates rapidly under exposure to the air, and it leaves a large quantity of clinker. The relative proportion of clinker would, of course, be only increased in coking, as all of the fusible matter originally contained in three tons of coal would thus become concentrated in two tons of coke. Hence, all attempts at coke-burning were long since abandoned, excepting on the Baltimore and Ohio Railroad, where a fair quality of coke is made from the Cumberland coal. The difficulty with clinker has been one of the greatest in the way of successful coal-burning in America. It has compelled the frequent disturbance of the fire, from both above and below; at times it would almost shut off the access of air, requiring then the utmost intensity of an adjustable blast to maintain the fire, and under these circumstances the fire-box plates were likely to become much injured by the heat at particular parts. Under the strength of the blast, the clinker would often fly to and completely close the ends of the tubes. Apart therefore from the waste, and the nuisance of smoke, there has been great difficulty

in keeping up steam when it was attempted to burn coal in the ordinary wood-burning engines. The forms of grates contrived to clear themselves of clinker have been numerous enough, and it is still necessary to employ a grate of the description mentioned in connection with the Rogers' coal-burning engines, in order successfully to burn the ordinary qualities of western coal. At one time considerable expectations were entertained that the Delano grate would obviate much of this difficulty but on trial it did not appear to afford any signal advantages. In its construction, an opening of, say, 12 by 18 inches was made nearly in the middle of an ordinary grate, beneath which was a sliding box, so placed that it might be pushed under this opening or be drawn back to be filled with fresh coal. A leaf or plate, projecting from one side of the box, kept the opening closed when the box was drawn back. Within the coal-box was a moveable piston, which, when the box was to be charged with coal, was lowered to its bottom, but which, on pushing the box under the opening in the grate, was raised, thus forcing the coal in at the bottom of the fire. Upon the Long Island, New York and Erie, and other roads, grates for burning coal have been formed of stout chains suspended across the bottom of the firebox, the flexibility of this arrangement being said to be very effective in keeping the bottom of the fire clear of clinker. On one of the Iowa railroads it was at one time the practice to cover the sides of the grate with a sloping pavement of firebrick, leaving only a portion of the grate, about 20 inches square, uncovered in the centre. It was said that with this arrangement, applied by Mr. Malden Wright, the draught was so localized that the clinker was fused in its most fluid state, so as to run freely through the bars. In a majority of coal-burning boilers, it is still found advantageous to close up several inches at the front ends of the grates, as also in many cases at the sides, forming a "dead-plate" upon which the coal may lie and become partially coked in mass before entering upon active combustion. The variable-exhaust, or adjustable-exhaust nozzles are used in most American coal-burners, and not one probably is without the steam-jet in the chimney, by which steam may be let on directly from the boiler to maintain a draught and keep down smoke whilst the engine is standing. In the Rogers' engines, Mr. W. S. Hudson has formed an annular chamber within the cast-iron base of the chimney, from which, when steam is admitted, it escapes through numerous small openings, forming a circular concentric sheet within the neck of the chimney.

In many of the arrangements thus hastily described there is considerable ingenuity, and, as an almost necessary consequence, a considerable degree of complication. It is not at all probable that the Dimpfel, Boardman, Phleger, or Bayley boilers can ever attain any considerable adoption, as even were they meritorious in themselves, their application to existing locomotives, of which full 9000 are now at work in the Union, would be very expensive if not impracticable. The problem of coal-burning promises to be solved by the selection of good coal, with careful and frequent firing; the arrangements in the furnace being such simply as to thoroughly mix and ignite the gas and air, and to keep the grates clear of clinker. There is abundant proof that no extensive structural modification of the ordinary wood-burning boiler is required for these results. Considering the extremely expensive nature of the fuel burned in American locomotives—the cost per train-mile in the eastern and in many other of the states, averaging fully three times that upon all the railways of Great Britain—it is altogether probable that the use of coal, already practised with much success, will become general in the next two or three years.

From the opportunities which the author has enjoyed in England for observing the action of the steam inducted air currents in locomotive fireboxes, as applied in Mr. D. K. Clark's arrangement, it is his conviction that similar means will be found to be the most effective in the end for burning coal in American engines. Extensive practice on English railways, proves that the mixture of air with the gas is thus rendered complete, the result being the entire prevention of smoke with an abundant command of steam. The facility with which this plan can be applied to existing stock is not its least merit.

POSTSCRIPT.

1.—ON THE COMPARATIVE STRENGTH, &c., OF STEEL AND WROUGHT IRON IN BARS AND PLATES.—An extensive and most important series of experiments on the Tensile Strength of various kinds of steel and wrought iron, by Messrs. Robert Napier & Sons, Glasgow, has recently been completed. The experiments were ably conducted by their Mr. David Kirkaldy, and the results have just appeared in full detail, with illustrations, in the *Transactions of the Institution of Engineers in Scotland*, 1858–59. The specimens, 538 in number, were all tested in precisely the same manner by means of a large steel-yard: weights being gradually applied until each specimen was torn asunder. In conducting these remarkable and original experiments, and in tabulating the results, every care seems to have been taken to develop impartially the peculiarities of the various specimens tested. The results, of which the following summary is an abstract, are both interesting and important; they represent the subject in a novel point of view, and form a record of the most recent attainments of the manufacturers of steel and iron, in producing materials qualified to bear the strain and fatigue incidental to modern works of construction.

GENERAL SUMMARY OF RESULTS OF EXPERIMENTS ON THE COMPARATIVE TENSILE STRENGTH, &c., OF VARIOUS KINDS OF STEEL AND WROUGHT IRON, BY MESSRS ROBERT NAPIER & SONS

Note.—All the pieces were taken promiscuously from Engineers' or Merchants' Stores, except those marked S, which were received from the Makers.

No. of Experiments on each.	District.	Names of the Makers or Works, and Description.	Breaking weight per square inch of original sectional area. Highest.	Lowest.	Mean.	Breaking weight per square inch of fractured area. Mean.	Contraction of area at Fracture.	Elongation, in parts of the length.	Characteristics of Fracture. (The subjoined figures express the per centage of the whole fractured section.)	
		STEEL BARS.	1.	2.	3.	5.	7.	9.	11.	
			lbs.	lbs.	lbs.	lbs.	per cent.	per cent.	Granular, per cent.	
6	Sheffield	T. Turton & Son, cast-steel for tools. Forged.	145,383	112,242	132,909	189,124	4·7	5·4	100	Wholly granular, fine, and semi-lustrous.
4		T. Jowitt, cast-steel for tools. "	148,294	117,719	132,402	151,857	12·8	5·2	100	
8		" cast-steel for chisels. "	137,979	112,331	124,852	150,243	17·0	7·1	100	
4		" double shear steel. "	125,321	106,747	118,463	147,396	19·6	13·5	97	Partly granular and partly fibrous, of a very fine silky lustre.
4		" cast-steel for drifts. "	130,447	96,658	115,882	147,570	21·5	13·3	78	
8		Bessemer, for tools. " S.	123,165	103,255	111,460	143,327	22·3	5·5	90	
4		Moss & Gambles, for rivets. Rolled S.	116,763	101,422	107,286	158,013	32·1	12·4	54	
4		Naylor, Vickers, & Co., for rivets. "	112,262	101,421	106,615	155,785	32·8	8·7	90	
4		Wilkinson, (L) Blister steel. Forged.	114,183	89,546	104,298	132,472	21·4	9·7	97	
4		Jowitt, cast-steel for taps. "	110,697	84,036	101,151	142,070	28·5	10·8	94	
4		Krupp, Dusseldorf, cast-steel for bolts. Rolled	94,208	86,054	92,015	139,434	34·0	15·3	49	
4		Shortridge, Howell, & Co. Homog. metal. Rolled.	99,570	82,218	90,647	142,920	36·6	13·7	30	
4		" " " " Forged.	94,752	84,794	89,724	121,212	26·0	11·9	92	
4		T. Jowitt, spring steel. "	82,719	65,156	72,529	95,490	24·1	15·0	20	Granular, fibrous, and crystalline.
6	Glasgow	Mersey Co., puddled steel. "	75,804	67,065	71,486	110,451	35·3	19·1	6	Granular and fibrous.
3		Blochairn. " Rolled	75,114	55,006	70,166	84,871	19·4	11·3	14	Granular and fibrous; irregular.
6		" " Forged.	71,501	42,564	65,255	80,370	19·0	12·0	0	
4		" " "	70,341	45,931	62,789	71,231	11·9	9·1	12	
88										
		IRON BARS.							Crystalline, per cent.	
4	Yorkshire	Low moor. Rolled bars, square.	62,298	59,202	60,884	117,147	48·5	1·89	1	Bright lightish gray fibre, compact and very fine.
4		" Planed. "	61,805	59,185	60,245	114,410	47·3	1·69	0	
4		" Rolled bars, round.	65,166	59,320	61,798	131,676	53·1	1·91	0	
4		" " for rivets.	62,451	58,228	60,075	125,775	52·2	1·35	0	
4		" Forged from bars.	67,676	64,871	66,392	115,040	42·3	1·11	0	
4		Bowling. Turned.	62,885	59,570	61,477	120,229	48·3	1·74	0	
4		" Rolled bars.	65,701	58,678	62,404	114,220	45·3	1·76	0	
4		Farnley. " "	64,133	59,642	62,886	127,425	50·6	1·74	0	
4	Staffordshire	Bradley & Co., (L) (charcoal). Rolled bars. S.	58,026	56,004	57,216	146,521	30·9	1·93	0	Bright gray; fibre very fine.
4		" " B.B. scrap. " " S.	59,998	58,571	59,370	123,905	52·0	2·02	0	
4		" " S C (crown) Rolled for rivets.	58,632	54,575	56,715	112,336	49·5	1·53	0	Dullish gray; fibre compact.
4		" " S C (crown) Rolled bars.	63,604	61,263	62,231	97,573	36·2	1·62	15	
4		Thorneycroft & Co., T N S. Rolled for rivets.	60,328	57,431	59,278	99,595	40·4	1·66	0	
4		Lord Ward, L (crown) W.R-O. " "	63,373	57,198	59,753	95,724	37·6	1·19	1	
24	Lanarkshire	Govan Extra B. Best. Rolled bars.	59,820	53,266	57,880	97,556	40·6	1·37	0	Brightish gray; fibre close and uniform.
20		Govan B. Best. " "	66,553	54,245	61,882	92,548	32·9	1·20	18	Grayish; close, but irregular
16		Govan * (common). " "	66,680	52,348	60,898	85,336	28·3	1·09	26	Loose and irregular.
9		Glasgow B. Best. " "	61,296	55,913	58,897	102,806	42·3	1·57	1	Brightish gray; fibre close and generally uniform.
5		" " Forged from bars.	60,605	56,316	59,045	80,053	26·2	0·67	24	
4		" Best Rivet. Rolled bars.	58,823	56,515	57,092	96,205	40·7	1·23	1	
4		Coatbridge Best Rivet. " "	33,577	59,013	61,723	96,267	35·9	1·47	0	
4		Blochairn " " "	59,900	58,506	59,219	89,279	34·3	1·32	0	
4		R. Solloch E. " " "	59,226	55,078	57,425	96,959	40·7	1·17	0	
4		St. Rollox " " "	68,848	47,248	54,981	77,383	26·8	1·13	42	
8		Ulverston " " "	59,330	47,095	53,775	104,680	48·6	1·45	0	Brightish gray; fibre close.
5		Mersey Co. Best. Forged from bars.	62,411	57,690	60,110	86,295	30·5	0·71	15	
4	Russ. Swedes	Per Eckman & Co., R F. Tilted bars.	48,987	47,384	47,855	121,065	60·5	1·67	0	Bright light gray; fine and very soft.
4		" " " " forged.	49,505	46,869	48,232	150,760	68·0	1·85	0	
4		Prince Demidoff, C C N D. Tilted bars.	55,190	44,600	49,564	73,118	32·1	0·80	18	Bright gray; very irregular.
4		" " " " forged.	65,516	52,334	56,805	77,632	28·1	0·92	47	
4		Hammered Scrap Iron from Forge.	54,070	52,665	53,420	94,105	43·2	0·94	0	Bright gray; close and fine.
4		Busheled Iron from turnings	57,526	54,070	55,878	72,531	22·9	0·73	5	
6		Cut out of a crank-shaft of hammered scrap iron, and reduced by machine and not on the anvil. Lengthways.	49,671	45,234	47,582	59,003	20·7	0·55	72	Light gray and lustrous.
2		" Crossways.	44,703	44,345	44,758	50,971	12·5	0·62	60	
195										

GENERAL SUMMARY OF RESULTS OF EXPERIMENTS—*Continued*

No. of Experiments on each	District.	Names of the Makers or Works, and Description.	Breaking Weight per square inch of original sectional area. Highest.	Lowest.	Mean.	Breaking Weight per square inch of fractured area. Mean.	Contraction of area at Fracture.	Elongation, in parts of the length.	Characteristics of Fracture. (The subjoined figures express the percentage of the whole fractured section.)	
			1.	2.	3.	5.	7.	9.		11.
		IRON STRAPS, &c.	lbs.	lbs.	lbs.	lbs.	per cent.	per cent.	Crystalline, per cent.	
4		Glasgow Ship Beam.	60,455	54,006	55,937	67,606	16·9	10·79	15	Gray; fibre close.
4		Dundyvan Ship Strap,	56,538	54,444	55,235	83,635	13·0	8·03	26	
3		Mossend Ship Strap.	51,985	39,534	45,439	50,459	9·2	6·15	45	Gray; fibre rather coarse.
6		Thorneycroft Ship Strap,	56,649	48,141	52,789	59,918	12·1	8·05	15	Lightish gray.
4		Consett Ship Angle-iron,	54,962	43,037	50,807	58,201	11·7	5·79	14	Dull gray; fibre loose.
4		Dowlais Ship Beam,	43,817	37,909	41,386	45,844	9·6	4·82	13	Dull gray; unlaminated.
25										

No. of experiments on each	District.	Names of the Makers or Works		See Note.*	Breaking weight per square inch of original sectional area. Highest	Lowest.	Mean.	Mean.	Breaking weight per square inch of fractured area. Mean.	Mean.	Contraction of area at Fracture.		Elongation.		Characteristics of Fracture.	
					1	2	3	4	5	6	7	8	9	10		11
		STEEL PLATES.			lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	per cent.		per cent.		Granular. per cent.	
4	Sheffield	T. Turton and Son. Cast.	S.	L	95,360	92,858	94,289	95,299	100,063	105,937	5·6	9·5	6·71	7·68	100	Wholly granular, fine, and semi-lustrous.
4		,, ,,	S.	C	99,952	92,788	96,308		111,811		13·4		9·64		100	
6		Naylor, Vickers, and Co. ,,	S.	L	87,972	76,772	81,719	84,435	104,232	108,125	21·4	21·7	17·50	17·41	40	Granular and fibrous; very fine.
6		,, ,, ,,	S.	C	95,196	82,425	87,160		112,018		22·0		17·32		24	
7		Moss and Gambles. ,,	S.	L	81,588	67,977	75,504	72,338	105,554	109,050	28·2	33·4	19·82	19·73	0	Wholly fibrous; very soft and fine.
3		,, ,,	S.	C	71,796	67,538	69,082		112,546		38·6		19·64		0	
5		Shortridge, Howell, & Co.	.	L	108,900	85,650	96,280	96,675	114,106	113,954	15·6	15·1	8·61	10·14	60	Granular and fibrous; very fine.
6		Homogeneous Metal.	.	C	105,732	84,211	97,070		113,802		14·6		11·66		73	
4		,, 2d quality.	S.	L	81,662	62,435	72,408	72,994	81,823	80,034	11·5	8·6	5·93	4·57	0	Laminated, fibrous, & slightly granular.
2		,, ,,	S.	C	84,724	62,435	73,580		78,245		5·7		3·21		6	
4	Liverpool	Mersey Co., puddled steel.	.	L	108,906	92,676	101,450	93,209	109,552	100,649	6·4	5·4	2·79	2·02	16	
4		(Ship plates). ,,	.	C	99,468	63,098	84,968		91,746		4·4		1·25		10	
3		,, "hard" ,,	S.	L	106,110	95,946	102,593	93,979	107,827	98,472	4·5	4·6	4·86	4·08	76	Granular and laminated; fibrous.
2		,, ,, ,,	S.	C	88,529	82,200	85,365		89,116		4·7		3·30		59	
2		,, "mild" ,,	S.	L	86,908	67,184	77,046	72,366	88,240	80,937	12·5	10·5	6·16	5·94	17	Laminated, fibrous, & slightly granular.
2		,, ,, ,,	S.	C	68,848	66,524	67,686		73,634		8·5		6·72		1	
2		(Ship plates.) ,,	.	L	78,020	65,045	71,532		77,520		7·5		3·57		1	
5	Glasgow	Blochairn, puddled steel.	S.	L	106,394	93,327	102,234	93,316	108,079	97,978	5·3	4·8	3·60	3·14	78	Granular and laminated; fibrous.
5		,, ,,	S.	C	89,447	81,047	84,398		87,877		4·2		2·68		49	
2		,, (Boiler) ,,	.	L	97,413	95,227	96,320	85,010	107,614	92,130	10·4	7·1	8·22	6·18	23	
2		,, ,,	.	C	73,606	71,792	73,699		76,646		3·8		4·14		18	
80																
		IRON PLATES.													Crystalline. per cent.	
4	Yorkshire	Farnley	S.	L	62,544	56,172	66,437	66,705	83,112	76,036	29·6	24·8	17·0	14·15	4	Colour generally uniform, of light brightish gray; fibre compact and very fine.
4		,,	S.	C	56,546	52,955	55,033		68,961		20·1		11·3		27	
7		,,	.	L	61,184	51,541	57,246	63,703	69,650	63,073	15·9	15·6	12·5	9·65	0	
10		,,	.	C	60,756	40,541	50,160		56,495		12·3		6·8		0	
5		Low Moor	.	L	57,881	47,426	52,000	51,257	64,746	61,065	19·7	15·9	13·2	11·25	0	
5		,,	.	C	55,368	47,426	50,515		57,383		12·1		9·3		0	
5		Bowling	.	L	53,488	51,443	52,235	49,338	61,716	55,862	15·9	11·1	11·6	6·75	19	
5		,,	.	C	50,138	43,074	46,441		50,009		6·9		5·9		8	
3	Staffordshire	Bradley and Co. S C	.	L	56,534	53,889	55,831	53,191	67,406	61,306	17·2	13·1	12·5	9·00	3	Dullish gray of various shades; fibre close and generally fine.
3		,, ,,	.	C	55,414	47,532	50,550		55,206		9·0		5·6		3	
6		,, ,, L.F.	.	L	60,985	54,687	56,996	54,123	66,858	61,464	15·0	11·8	13·0	9·45	12	
6		,, ,, ,,	.	C	55,697	47,410	51,251		56,070		8·6		5·9		9	
3		,, ,,	.	L	60,697	51,295	55,708	52,586	65,652	60,827	14·9	11·5	10·7	7·90	17	
3		,, ,,	.	C	51,023	47,238	49,425		54,002		8·1		6·1		15	
7		T. Wells, Best Best	.	L	54,406	41,002	47,410	47,020	61,521	49,935	6·7	6·8	4·0	3·70	10	Dull gray; fibre rather coarse.
7		,, ,,	.	C	49,441	42,581	46,630		48,348		4·9		3·4		10	
3		K.B.M.	.	L	51,285	43,232	46,404	45,584	51,898	49,893	10·2	8·3	6·1	5·20	1	
3		,,	.	C	45,402	44,195	44,764		47,891		6·4		4·3		5	
3		Consett	.	L	54,403	47,618	51,245	48,979	59,183	55,616	13·1	11·7	8·9	7·68	42	Gray; fibre loose.
4		,,	.	C	47,613	46,062	46,712		52,050		10·2		6·4		27	
6	Lanarkshire	Glasgow, Best Boiler	.	L	56,317	48,016	53,849	51,349	60,522	56,387	11·0	8·3	9·3	6·95	43	Gray; fibre rather coarse; crystals fine.
6		,, ,,	.	C	52,959	45,761	48,848		52,252		6·6		4·6		36	
6		Glasgow, Ship	.	L	53,370	37,474	47,773	46,064	49,816	47,580	4·8	4·1	3·6	2·88	48	Gray; fibres coarse, and crystals generally do.
6		,, ,,	.	C	49,842	32,150	44,355		45,343		3·4		2·1		49	
6		Makers' stamp uncertain	.	L	49,838	43,290	47,598	44,140	53,182	48,304	9·8	7·4	5·9	4·20	16	Dull gray; fibre rather coarse.
6		,, ,,	.	C	44,512	37,330	40,682		43,426		5·0		2·5		10	
3		Mossend, Best Best	.	L	43,992	43,012	43,433	42,445	46,038	44,830	6·7	5·3	3·3	3·10	20	Gray; fibre generally coarse.
3		,, ,,	.	C	43,875	38,007	41,456		43,622		4·9		2·9		16	
6		Govan, Best.	.	L	49,677	38,398	43,942	41,743	45,886	43,255	6·0	4·3	3·4	2·40	12	
6		,, ,,	.	C	43,069	36,460	39,544		40,624		2·6		1·4		10	
150																

* L denotes that the strain was applied *lengthways* of the plate; C, *crossways*.

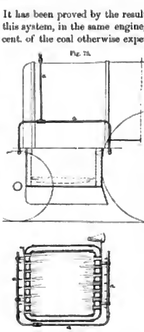
II.—On the Progress of the Substitution of Coal as Fuel for Coke in Locomotives.—In the north of England and the south of Scotland, coal is to a very great extent substituted for coke. The introduction of air, for the purpose of consuming the smoke, is effected through the doorway, and is deflected upon the surface of the fuel by means of a "shovel" or inverted scoop, or a baffle-plate, inserted obliquely downwards within the firebox. This mode appears to have been indebted for its extensive adoption to its extreme simplicity, as much as to a certain degree of efficiency which it undoubtedly possesses. But it is remarkable, notwithstanding the degree of skill and apparent success with which the "shovel" is worked, and the satisfaction with which its performance is regarded by those who use it, that the railway smoke-nuisance is becoming a very serious annoyance to the public, and that examples are now becoming frequeot of the public taking the matter into their own hands, judging for themselves, and trying it at law. The efficient and perfect use of coal in locomotives is not yet attained—the practice generally is in a state of transition; the reduction of the expenditure is the first object, the abatement of the nuisance is the second.

Nevertheless, the system of the steam-inducted air-currents, by D. K. Clark, has been, and is now, at work with entire success, both in point of performance and in point of economy. It is applied to the whole of the locomotive stock of the Great North of Scotland Railway, under the superintendence of Mr. William Cowan, the locomotive manager; and is not alone accepted by the Railway Company, as a complete practical solution of the problem of smoke-prevention with the use of coal, but also appears to be accepted by the travelling public with the same unconditional appreciation. The system, as in operation on that line, has been officially inspected by a committee of the British Association, on the occasion of their recent meeting at Aberdeen, aod it has been pronounced by the committee to be entirely satisfactory in its operations. It is also in successful use in the engines of the Londonderry and Enniskillen Railway, and the North London Railway—the latter of which is a metropolitan line—where smoke had need be very seldom seen and rarely smelt.

Mr. Clark's system is now reduced into a much simpler and more compact form, suggested by the extended experience it has commanded, than as originally applied in the first essay, on the Eastern Counties Railway, as depicted in Figs. 54, 55, page 30*. Two single rows of air-openings, about 2 inches diameter, are inserted, one at the front and one at the back of the firebox, with a steam-nozzle to each, $\frac{1}{16}$th inch diameter, set off on the branches of a small steampipe led from the crown of the firebox, and controlled by a single cock or valve. (See Fig. 75.) The steam is kept well up, and on this system a less weight of coal than of coke is consumed in the performance of the same duty; so that the saving of working expense is more than the entire differeuce in cost of the two fuels.

It has been proved by the results of comparative trials of this system, in the same engine, that upwards of 18 per cent. of the coal otherwise expended, when the smoke is not so consumed, is economized by the process of burning the smoke. Mr. Patrick Stirling found, on the contrary, by comparative trials with and without the use of Lee's system of smoke prevention, that more coal was consumed in the same engine when the smoke was thus burned, than when the system was not in operation:—a disadvantage which probably attends more or less all systems of smoke-burning, by introducing air in bulk through the doorway.

Fig. 75.



c, c, Steam pipe.

III.—Feed-water Heating Apparatus.—Mr D. K. Clark has recently introduced a simple, compact, and efficient method of heatiog the feed-water, applicable to all classes of steam-boilers. It operates by heating the feed-water in detail, or in small successive quantities, by the forcible and immediate intermixture of currents or jets of water and steam travelling together. One or more jets of steam are discharged freely and directly through a pipe into which also the water to be heated is delivered, and through which it is passed in conjunction with the steam. In this confined passage the steam, in virtue of its initial velocity, forcibly impinges upon, mixes with, aod disperses the water, and is quickly condensed, and the water is proportionally raised in temperature. The supply of steam may be taken from the boiler direct, or from the exhaust-passages of steam engines connected therewith. In mechanical detail the apparatus is simple, and in the first experimental trial of the plan, in connection with a stationary engine, the whole process was consummated within the compass of a heating tube, 2½ inches diameter and 20 inches long. A 1¾-inch nozzle was attached to the exhaust-pipe, which was 4 inches in diameter, and was joined to the upper end of the heating tube, and the exhaust steam blown straight down into it. Cold water at 60° was introduced at the upper end of the tube, through a number of small perforations, and, meeting the steam-current, condensed the whole or the greater part of it, and was delivered at the lower end, at temperatures varying from 180° to 212°. Experiments are in progress to test its applicability to locomotives.

DESCRIPTIONS OF THE LARGE ENGRAVINGS

IN

RECENT PRACTICE.

PLATE XXXI.*

TANK-LOCOMOTIVE BY I. K. BRUNEL, LONDON. This engine, made by the Vulcan Foundry Company, Warrington, for the Vale of Neath Railway, was designed by the late Mr. Brunel, to work the heavy mineral traffic of the Vale of Neath Railway, on the 7-feet gauge. It is placed on six wheels, 4 feet 9 inches diameter, all coupled, and 15 feet 3 inches apart between the extreme axles. It has inside cylinders, 18 inches diameter, 24 inches stroke; and carries the water in a saddle-tank, on the top of the boiler, and coke behind the boiler. It weighs 40 tons in full working trim.

The firebox is 4 feet 10½ inches long, and 5 feet 8 inches wide at the grate, giving an area of 27½ square feet of grate; and is abont 4 feet 9 inches deep above the grate. It is only 4 feet 6 inches wide at the top. The firebox is of ½-inch copper plate, except the tube-plate, which is ⅞ inch thick. The firebox-shell is 5 feet 4½ inches long outside, 5 feet 1 inch wide at the centre, and 6 feet 2½ inches wide at the bottom; copper stay-boits, 4 to 4½ inches pitch. The unusual taper of the sides thus employed is favourable for liberating the steam formed in the water-spaces, and leaves room for the fittings of the engine on the outside. The barrel of the boiler is 10 feet 6½ inches long, 5 feet 1 inch smallest diameter at firebox, of ½-inch plates, lapped like a telescope, and expanding towards the smokebox. The tube-plate is ¾ inch thick. There is no angie-iron in its construction. The rivets are ¾ inch diameter, at 1⅞ inch pitch. The flue-tubes are of brass, 256 in number, 10 feet 9 inches long, between plates, 2 inches outside diameter, ⅝ inch clearance. Their sectional area is 5·585 square feet. The heating surface is as follows:—

Firebox, ...	112·0	square feet.
Tubes, inside, ...	1305·6	"
Total, ...	1417·6	"

The smokebox is formed as part of the barrel, 3 feet 4 inches long, 5 feet 4 inches diameter, of ½-inch plates. The chimney is 1 foot 7 inches diameter outside, and 14 feet 10 inches high above the rails. The safety-valves, two in number, are conical, 4 inches diameter, 12·56 square inches area, with levers as 12·56 to 1.

The cylinders are, as already stated, 18 inches diameter, and 24 inches stroke, at 43-inch centres apart; they are 1¼ inch thick. The steam-ports are 15 inches wide, 1½ inch long; the exhaust-port is 3⅝ inches long; the bridges ¾ inch. The travel of valves is 5 inches, the lap 1¼ inch, clearance inside ⅛ inch, lead $\frac{1}{16}$ inch. The valve-gearing is Mr. Henry Dubs' wedge-motion, and not the usual link-motion. The eccentrics, one to each valve, are of wrought iron, with white metal lining, have 5 inches maximum throw, 20¾ inches diameter, and 2½ inches thick. The piston is 4½ inches deep, with 2½-inch packing in two rings, cut at one place; the rod is 3 inches diameter. The steam is led to the valve-chest by two 3-inch copper pipes to each chest; the blast-pipe is of cast iron, 6 inches diameter, with changeable brass nozzles, 6 and 6½ inches diameter, 2 inches above uppermost row of tubes. The regulator is a cast-iron slide, in the smokebox. There are two donkey-pumps, one on each side of the firebox, with 3⅝-inch plunger; 4 inches stroke.

The guide-bars are in two pairs to each cylinder, 3 feet 10 inches long, 3 inches broad; the slide-blocks are 10 inches long. The cross-head-bearing for connecting rod is 3 inches diameter, 3½ inches long. The connecting-rod is about 6 feet 1½ inch long, or above six times the length of the crank.

The wheels are 4 feet 9 inches diameter. The tyres are 5½ inches broad, 2¾ inches thick, flanges 1 inch high. There are 16 spokes, 4 by 1¼ inches at nave, 3¼ by 1½ inches at the rim. The nave is 3¾ inches thick round the axle, and 7 inches deep. The crank-axle is 8¾ inches square between the wheels; the other axles are 7 inches diameter; and all are 9 inches diameter in the wheels. The bearings are 7½ inches diameter, by 10 inches long. The crank-journals are 9 inches, by 5 inches long. The bearing-springs for the front and middle axles are 3 feet long, 4 inches broad, having seventeen plates ⅜ inch thick. and one plate ⅝ inch. The hind-springs are of india-rubber, and each consists of three cylinders, one 9 inches diameter, two 6 inches. The frame-plates, one on each side, are 17 inches deep, 1⅛ inch thick, with axle-guards forged on.

The water-tank is semicircular, or saddle-form, 19 feet 1 inch long, 8 feet 1 inch wide, 4 feet 8 inches deep. Plates outside weigh 5 lbs. per square foot; inside plates $\frac{3}{16}$ inch thick. It holds 1500 gallons.

This engine can take up an incline of 1 in 90, a train of 25 loaded waggons, 15 tons each, or 375 tons total, and with the engine 415 tons gross; equivalent to a gross weight on a level of 1245 tons.

PLATE XXXII.*

PASSENGER AND GOODS LOCOMOTIVES, BY JOHN HAWKSHAW, LONDON.—The engines here represented were designed by Mr. Hurst, under Mr. John Hawkshaw, for the Lancashire and Yorkshire Railway. For working the heavy traffic of this line, these engines were made uncommonly strong in all their working parts, and they, particularly the goods engines, have worked well. The following are leading dimensions:

Passenger Engine.—Firebox 3 feet 6 inches square, with 12½ square feet of grate surface; plates ⅝ inch thick. The

chimney is contracted to 11 inches diameter at the throat, in order to increase the effective action of the blast. The cylinders are 15 inches by 20 inches stroke, with steam-ports 10 by 1$\frac{1}{4}$ inches. The cylinders are outside, the framing is inside, and the driving-wheels are 5 feet 9 inches diameter. The extreme axles are 13 feet 2 inches apart. The regulator is double-beat. The valve-gear has the ordinary link-motion.

Goods Engine.—The cylinders are 15 inches by 24 inches stroke, inside. The six wheele are 4 feet 9 inches diameter, all coupled, with 13 feet 3 inches length of wheel-base. The firebox is 3 feet 9$\frac{1}{4}$ inches long, by 3 feet 6 inches wide;—moderate dimensions, and contrasting strongly with those of the Vale of Neath tank-engine.

PLATE XXXIII.*

Long-Boiler Locomotives, by Robert Stephenson & Co., Newcastle-on-Tyne.—The main distinguishing features in each of these engines are, the overhung firebox, and great length of flue-tubes. The weight is well distributed on the wheels, and the peculiar design, particularly in the passenger engine, is greatly conducive to simplicity and strength. The boilers are designed on sound principles: a moderate size of firebox, a moderate number of flue-tubes, and great length of flue:—a practice initiated by those engineers.

Passenger Engine.—The cylinders are 14 inches diameter, and 22 inches stroke; driving-wheels 6 feet, carrying wheels 3 feet 6 inches, at 12 feet 4 inches length of wheel-base. The firebox has 9 square feet of grate. There are 103 flue-tubes, 2 inches diameter, 13 feet 11 inches long; the barrel of the boiler being 13 feet 8 inches long, and 3 feet 3 inches diameter. The following are the heating surfaces:—

Firebox surface, ...	48	square feet.
Tube surface, inside, ...	688	"
Total, ...	736	"

Goods Engine. — The cylinders are 16 inches by 24 inches stroke; six wheels, all coupled, 5 feet diameter, 12 feet extreme centres. Grate area 13·7 square feet; 133 tubes, 2$\frac{1}{8}$ inches, and 13 feet 10 inches long. The heating surface is as follows:—

Firebox surface, ...	82	square feet.
Tube surface, inside, ...	932	"
Total, ...	1014	"

PLATE XXXIV.*

Passenger and Goods Locomotives, by R. & W. Hawthorn, Newcastle-on-Tyne. — These engines are made with inside cylinders, and double framing, inside and outside the wheels, extending the entire length of the engine. The introduction of volute springs over the hind driving-axle of the goods engine, simplifies the arrangement. The moderate number of flue-tubes, within a comparatively spacious barrel, has always been a good feature in Messrs Hawthorn's engines, and accounts for the generally superior steaming power of their engines.

Passenger Engine. — Boiler 10 feet long, 4 feet diameter, plates $\frac{5}{16}$ inch thick; firebox-shell 5 feet 1$\frac{7}{8}$ inch long, plates $\frac{1}{2}$ inch thick; smokebox tube-plate $\frac{7}{8}$ inch thick; firebox of copper, $\frac{1}{2}$ inch thick; tube-plate where drilled for tubes 1$\frac{1}{8}$ inch, 4 feet 6 inches long, 3 feet 5 inches wide, 5 feet high above grate-bars, with cross-water way or midfeather. Ash-pan of $\frac{1}{4}$-inch plate, fitted with damper. Inside stays: firebox stayed with copper screw-stays, $\frac{7}{8}$ inch diameter, placed 4-inch centres, and rivetted over at each end; nine forged iron roof-stays on top of box, linked to shell; eight through tie-rods, 1$\frac{1}{4}$ inch diameter, and three tie-rods 1$\frac{1}{8}$ inch diameter from back plate of shell to crown of barrel. Tubes: 174 brass tubes, 2 inches diameter outside; No. 9 wire-gauge at firebox end, and tapering to No. 12 at smoke-box end, fixed in tube-plates, with turned steel ferrules at each end; venetian blind damper at end of tubes, worked from foot-board. Rivets for joints under steam pressure $\frac{3}{4}$ inch diameter, 1$\frac{7}{8}$ inch pitch.

Frame composed of two outside and two inside frames, with buffer-beams; outside frames of oak, 10 inches by 4$\frac{1}{2}$, with a $\frac{7}{16}$-inch plate on each side, made with axle-guards and cast-iron guides. Inside frame-plates of malleable iron, 9 inches by 1 inch, the full length between buffer-beams, with guards for driving-axle, and malleable iron guides; buffer-beams of oak, with a $\frac{5}{8}$-inch plate on front side; front beam 16 inches by 6 inches, hind 11 inches by 6 inches; two draw-plates, $\frac{1}{2}$ inch thick, rivetted to firebox-shell, and fastened to inside frames with bolts and nuts.

Wheels and axles of malleable iron; leading and trailing wheels 4 feet diameter; driving-wheels 6 feet 6 inches; extreme centres 15 feet; crank-axle with four bearings, 6$\frac{3}{4}$ inches diameter between cranks; leading and trailing axles 5$\frac{1}{2}$ inches diameter, with two bearings; bearings double-coned; axle-boxes of cast-iron, with brass bushes, except inside boxes, which are solid brass; springs of steel plates, 4 inches by $\frac{3}{8}$ inch, with $\frac{1}{2}$-inch back-plates; 3 feet centres; leading and outside driving-springs linked by compensating lever.

Cylinders and valve-chest of cast iron, in two pieces, bolted together and to inside frame-plates; diameter 16 incnes, stroke of piston 22 inches, steam-ports 1$\frac{1}{4}$ inch by 14 inches, exhaust 2$\frac{3}{4}$ inches by 14 inches; lap of slide-valve 1$\frac{1}{8}$ inch, lead $\frac{1}{16}$-inch; piston of cast iron, with brass packing. Eccentrics of cast iron, with brass straps; expansion-link 2 inches thick; all the working eyes steeled, and the pins of steel, all properly hardened. Regulator of cast iron, with brass slide, placed in smoke-box; steam-pipe of copper, extending the full length of boiler, and pierced on the top side with slot-holes for the admission of steam. Blast-pipe and feed-pumps of cast iron, with copper top orifice, 4$\frac{1}{2}$ to 5 inches diameter. Feed-pumps of brass, bolted to motion bar; steadiment, and inside frame-plates fitted with brass ball, clacks, glands, and bushes; ram of malleable iron, 1$\frac{3}{4}$ inch diameter, worked from cross-head; feed and suction pipes of copper, fitted with air-vessel.

Goods Engine.—Boiler: firebox-shell of $\frac{7}{16}$-inch plates; firebox of $\frac{1}{2}$-inch copper plates; tube-plate, where drilled for tubes, $\frac{7}{8}$-inch; box 4 feet 6 inches long, 3 feet 5 inches wide, 4 feet 9 inches high above grates; barrel of $\frac{7}{16}$-inch plates, 3 feet 11 inches diameter, 10 feet long. Inside stays: firebox stayed with $\frac{7}{8}$-inch copper screw-bolts, rivetted over at both ends, 4-inch centres, and nine roof-stays linked to

shell; eight through 1¼-inch tie-rods, and three tie-rods 1¼ inch diameter from back-plate to crown of barrel. Tubes: 158 brass tubes, 2 inches diameter outside, No. 10 wire-gauge at firebox end, tapering inside to No. 12 wire-gauge at smokebox; tubes fixed with steel turned ferrules at each end. Smokebox of $\frac{5}{16}$-inch plate; tube-plate ¾ inch thick. Rivets for joints under steam-pressure ¾ inch diameter, 1⅞ inch pitch.

Frame composed of two inside longitudinal plates, extending between buffer-beam and buffer-beam, 11 inches deep by 1⅛ inch thick, deepened to 19½ inches where cylinders are fixed. Axle-guards for leading and trailing axles solid on the frame-plate; axle-guards for driving-axle formed by rivetting on each side of frame a ⅝-inch plate; axle-box guides of cast-iron. Buffer-beams of English oak, 16 inches deep by 6 inches thick, with $\frac{5}{16}$-inch plate on front sides; hind-beam 13 inches by 6 inches, with $\frac{5}{16}$-inch plate. Outside frame 6 inches by $\frac{5}{16}$, with strong 2½-inch angle-iron, extending the full length of the engine, and attached at each end to buffer-beam, and by stays to inside frame.

Wheels and axles of malleable iron, all coupled, 4 feet 6 inches diameter; crank and plain axle with two bearings, each 6½ inches diameter by 6¾ inches long; outside cranks formed solid with wheel, and fitted with crank-pins 3 inches diameter. Axle-boxes of cast iron, fitted with brass bushes. Springs of steel plates, ⅜ inch by 4 inches, with back-plates, ½ inch; 2 feet 6 inch centres. Trailing springs volute, 5½ inches diameter, 8 inches high, two being placed above each bearing; all the springs are fitted with screws, for adjustment. Cylinders and valve-chest of cast iron, in two pieces bolted together and to inside frame-plates; diameter 16 inches, stroke of piston 24 inches, steam-ports 1¼ inch by 14 inches, exhaust 3½ inches by 14 inches, lap of valve 1⅛ inch, lead $\frac{3}{16}$ inch; piston of cast iron with brass packing; rod 2½ inches diameter. Eccentrics of cast iron, with brass straps; expansion-link 2 inches thick; slide-valve of brass; reversing-gear shaft 3 inches diameter, with bearings on the motion-plate, carrying links, and balance-weight. Regulator cast iron, placed in dome; with vertical face at upper end, two posts and slide-valve of brass, joined to copper pipe going to smokebox and cylinder; blast-pipe of cast iron; blast-orifice 4½ inches diameter. Feed-pumps of cast iron, bolted to motion-plate and inside frame-plates; fitted with brass ball, clacks, glands, and bushes; ram of malleable iron, 2 inches diameter, worked from cross-head; feed and suction pipes of copper, 2 inches diameter.

PLATES XXXV.*—XXXVIII.*

Locomotives made by Messrs. Beyer, Peacock, & Co., Manchester.—These engines are characterized by elegance and finish, in general form and arrangement, and in detail. The broad and comprehensive slab frame-plate is here noticeable. It was first introduced by Mr. Beyer, many years since, in the engines made by the old-established firm of Sharp Brothers & Co. (now Sharp, Stewart, & Co.), and is now generally adopted in English practice. The short cast iron blast-pipe, reaching just above the level of the upper row of flue-tubes, is also noticeable. This level of blast-pipe gives the best results, creating a superior draft with a wide orifice, as compared with higher situated blast-orifices, and was first arrived at by Mr. Peacock, by means of a series of well-arranged experiments: it is now commonly adopted. The tank-locomotive is, in general design and proportions, the production of Mr. D. K. Clark; the constructive details are by the makers. This engine can take a gross load of 200 tons behind it, up an incline of 1 in 59, with curves, at 10 miles per hour, equivalent to a gross load of 900 tons on a level. It is made with a moderate firebox, and a moderate number of long flue-tubes, spaced well apart, on the principles advocated by the author. It works very well, and has at all times an abundant supply of steam, and is economical in fuel.

Passenger Engine.—The cylinders are 16 inches diameter, 20 inches stroke; driving-wheels 6 feet 6 inches diameter, the leading and hind wheels are 3 feet 6 inches diameter, and are of 14 feet 6 inches centres. The crank-axle is 6½ inches diameter at the middle, and at the journals, which are 7½ inches long, the throws of the cranks are 4 inches thick and 10 inches broad—being strong yet elastic. The axle is 8 inches diameter in the wheel-cases. The journals of the fore and hind axles are 4½ inches diameter, and 8 inches long. The firebox is 3 feet 6 inches wide, and 4 feet long, having 14 square feet of grate surface. There are 171 tubes, 2 inches diameter, 10 feet 4½ inches long, at ½-inch clearance, in a barrel 3 feet 11 inches in diameter, giving abundance of water room about the tubes. The blast-orifice is 4½ inches diameter.

Goods Engine.—The cylinders are 16 inches by 24 inches stroke; six wheels, all coupled, 5 feet in diameter, at 15 feet 6 inches extreme centres. The firebox is 4 feet 3 inches long, by 3 feet 6 inches wide at the grate, giving a grate area of about 15 square feet. There are 191 flue-tubes, 2 inches outside diameter, and 11 feet 7½ inches long, in a barrel 4 feet in diameter. Blast-orifice 4½ inches.

Tank-Locomotive.—Cylinders 15 inches by 24 inches stroke; four wheels, coupled, 4 feet 6 inches diameter, at 8 feet 6 inches centres apart. The firebox is 3 feet 2 inches long, by 3 feet 6 inches wide at the grate, which has 11 square feet of area. There are 149 brass tubes, 1¾ inch outside diameter, and 11 feet 4 inches long, at fully ⅝-inch clearance, in a barrel 3 feet 7 inches diameter. The water-tank is below the boiler. The axles are 6 inches diameter, and 8 inches in the wheels, and have journals 6½ by 8 inches long. The engine is 25 tons weight in working order, and has 15 tons on the driving-wheels, and 10 tons on the leading-wheels.

PLATE XXXIX.*

Passenger and Goods Tank-Locomotives, by the Vulcan Foundry Company, Warrington.—These engines have inside and outside cylinders respectively, and are fitted with Mr. Dubs' wedge-motion. Saddle-tanks are placed on the top of the boiler, and are so formed as to finish uniform with the firebox.

Passenger Engine.—The cylinders are 13 inches by 20 inches stroke; driving-wheels 5 feet 3 inches, extreme wheels 3 feet 6 inches, at 12 feet 9 inches centres. The firebox is 3 feet 6½ inches long, by 3 feet 5½ inches wide at the grate, which has 12½ square feet area. The barrel of boiler is 10 feet long, telescopic, and 3 feet 10½ inches

diameter, at the small end next the firebox. There are 158 brass tubes, 10 feet 3 inches long, 1¾-inch outside diameter, at ⅜-inch clearance. Their united sectional area is 2·99 square feet. The heating surface is as follows:—

Firebox, ...	64·0 square feet.
Tubes, inside, ...	712·6 „
Total, ...	776·6 „

There are four steam-pipes of copper, 2¼ inches diameter. There are two 4-inch safety-valves. The tank holds 450 gallons. The gauge of the way is 5 feet 3 inches.

Goods Engine.—The cylinders 16 inches by 20 inches. Wheels, four coupled, 4 feet 7 inches diameter. Firebox 4 feet long by 3 feet 6 inches, giving 14 square feet area of grate. There are 207 tubes, 1¾ inch diameter.

PLATE XL.*

GOODS LOCOMOTIVE, BY ALEXANDER ALLAN, PERTH.—This engine has outside cylinders, with four coupled wheels, on a system very popular in Scotland. The firebox is set out at the upper part of the sides, next the tube-plate, in order to admit the greatest possible number of tubes into the barrel, and to obtain the greatest possible quantity of heating surface. The crank-pins are very solidly placed in the wheels, and are well worthy of study. The buffer-beams are hung entirely clear of the cylinders,—another good feature. The cylinders are 16 inches by 20 inches, four coupled wheels, 4 feet 7 inches diameter. There are 212 brass tubes, 1¾ inch outside diameter, 10 feet 7 inches long. The grate is 3 feet 2 inches wide, and 3 feet 6 inches long, having above 11 square feet of area. The heating surface is as follows:—

Firebox, ...	65 square feet.
Tubes, ...	984 „
Total, ...	1049 „

PLATE XLI.*

GOODS LOCOMOTIVE, BY ROBERT SINCLAIR, CONSTRUCTED BY NEILSON & CO., GLASGOW.—This is a spanking engine, with horizontal outside cylinders, and four coupled wheels, according to the principles long and ably worked out by Mr. Sinclair, who holds that four coupled wheels, properly weighted, are, upon the whole, superior in general efficiency to six coupled wheels. The position of the steam-dome, over the front part of the firebox, is good: it equalizes the draft of steam from the different parts of the boiler towards the dome. The wheels are large, 6 feet 1 inch diameter, and the cylinders are 18 inches by 24 inches: from these dimensions superior results are anticipated. There is also a heavy cast-iron footplate, to give hind-weight,—another good feature. The firebox is 3 feet 1½ inch wide, and 4 feet long, giving 12½ square feet area of grate. The seams of the boiler are double rivetted throughout. The tubes are 11 feet 6½ inches long. The wheels are at 15 feet 1 inch extreme centres. The steam-ports of the cylinders are 1¾ inch long by 12 inches wide,—unusually large.

PLATE XLII.*

EXPRESS TANK-LOCOMOTIVE, BY GEORGE ENGLAND & CO., LONDON.—This engine is well adapted for quick express trains of moderate length. It takes seven carriages, at a speed of 36 miles per hour, on a run of 47½ miles, with six stoppages, with a consumption of 9·7 lbs. of coke per mile. It is capable of taking seven loaded carriages, and one luggage van, up an incline of 1 in 85, in good style. The cylinders are 9 inches by 12 inches stroke, the driving-wheels are 4 feet 6 inches diameter, and the extreme centres of leading and hind axles are 12 feet 8 inches apart. The firebox is 2 feet long, and 3 feet 1 inch wide at the grate, giving an area of grate equal to above 6 square feet. There are 105 tubes, 1¾ inch diameter, 9 feet 8 inches long, in a barrel 2 feet 5 inches diameter.

PLATE XLIII.*

PASSENGER LOCOMOTIVE, BY SHARP, STEWART, & CO., MANCHESTER.—This engine comprises several novelties. The ordinary guide-bars are superseded by a circular guide, within which a prolongation of the piston-rod is carried. The steam is passed round the base of the chimney on its way to the cylinders, in order to be superheated. There is but one steam-pipe from the heating chamber, upon which the regulator is placed. The ordinary pumps are superseded by a donkey-engine at the side of the firebox, and an auxiliary pump is fixed under the boiler, to be worked from the valve-eccentrics in cases of need.

The cylinders are 16 inches diameter, 22 inches stroke; four coupled wheels 5 feet, fixed wheels 3 feet 6 inches, and extreme centres of axles 14 feet 6 inches apart. The firebox is 4 feet 2 inches long and 3 feet 4½ inches wide, giving 14 square feet of grate. There are 156 flue-tubes, 2 inches diameter, 10 feet 7½ inches long.

PLATE XLIV.*

TANK-LOCOMOTIVES, BY ROBERT STEPHENSON & CO., AND BY GEORGE ENGLAND & CO.—The first of these engines has four coupled wheels, and a four-wheel bogie under the fore part, to pass easily round curves. The water-tank is placed conveniently under the footplate, and the fuel is stowed away behind the engineman. The light four-wheel coupled tank-engine, on the same plate, by George England & Co., is designed for a short local traffic in minerals and agricultural produce. The framing is strong, and as the boiler is small, there is plenty of room under it for the water-tank, and free access to all the working parts of the machinery, which is simple.

Tank-Locomotive, with Bogie.—The firebox is of copper plate, $\frac{7}{16}$ inch thick, 3 feet 5½ inches long, and 3 feet ¾ inch wide at the grate, which has 10·52 square feet area. The firebox-shell is of $\frac{7}{16}$ inch iron plate, with water-spaces, 2½ inches at bottom, 3 inches at top. Copper stay-bolts at 4-inch centres. The barrel of the boiler is 10 feet long, 3 feet 7 inches diameter, of $\frac{7}{16}$-inch plate. Rivets ¾ inch, at 1¾ inch pitch. The flue-tubes, of brass, are 145 in number, 10 feet 4 inches long, 1⅞ inch outside diameter, and ¼ inch clear, of No. 12 to 14 wire-gauge; sectional area 3·05 square feet.

Heating surface of firebox, ...	65 square feet.
„ tubes, ...	662 „
Total, ...	727 „

The smokebox is of ¼-inch plates, ⅝-inch rivets, at 2¼-inch centres. The chimney is 16 inches diameter at

bottom, 14 inches at top, of $\frac{5}{16}$-inch plate, $\frac{3}{4}$-inch rivets, at $1\frac{3}{4}$-inch centres.

Steampipe 5 inches diameter. Blast-pipe, regulating, $3\frac{7}{16}$ and $5\frac{1}{2}$ inch orifice, at 6 inches below crown of smoke-box; $7\frac{1}{2}$ inches diameter at bottom. Safety-valves, two, 4 inches diameter, with levers having 3-inch and $37\frac{1}{2}$-inch centres:—the leverage being as 1 to $12\frac{1}{2}$, and the area of the valve $12\frac{1}{2}$ square inches.

The cylinders are 15 inches by 22 inches, at $29\frac{1}{2}$-inch centres, thickness $\frac{3}{4}$ inch; piston of brass, $4\frac{1}{2}$ inches deep; packing $2\frac{1}{4}$ inches, rod $2\frac{3}{4}$ inches diameter.

Steam-ports 13 inches by $1\frac{1}{4}$ inch, exhaust-ports $2\frac{1}{2}$ inches, bridge 1 inch. Valve, travel $4\frac{1}{2}$ inches, lead $\frac{3}{16}$ inch, lap 1 inch outside, $\frac{1}{16}$ inch inside, spindle $1\frac{1}{2}$ inch. Eccentrics of cast iron, $6\frac{1}{2}$-inch throw, 15 inches diameter, $2\frac{3}{4}$ inches wide. Regulator, swan-neck, with $19\frac{1}{2}$ square inches of steam-way. Motion-bars in two pairs, $2\frac{1}{2}$ inches broad; slide-blocks 8 inches long. Connecting-rod bearing $2\frac{3}{4}$ by $2\frac{1}{4}$ inches long.

Driving and coupled wheels 5 feet 3 inches diameter; tyre 6 inches broad, and plain for driving and 5 inches for hind wheels, $2\frac{1}{4}$ inches thick; 16 flat spokes. Nave $3\frac{1}{4}$ inches thick round axle, and $7\frac{1}{4}$ inches deep. Driving-axle cranked, 6 inches diameter at middle, 7 inches in wheel, $6\frac{1}{2}$ by 4 inches long at crank-pin, bearing $6\frac{1}{2}$ by 6 inches long; hind-axle same sizes. Bogie-wheels 3 feet diameter, 10 spokes, nave $2\frac{3}{4}$ inches thick round the axle, 6 inches deep; axles $4\frac{1}{2}$ inches at middle, $5\frac{1}{2}$ inches in wheels, bearings 4 by 8 inches, 6 feet apart.

Springs for coupled wheels, 3 feet long, 4 inches broad, nineteen plates, $7\frac{5}{16}$ inches deep; for bogie, 4 feet 6 inches long, 4 inches broad, $7\frac{1}{16}$ inch deep, having eight long plates, $\frac{1}{2}$ inch, seven short plates $\frac{5}{16}$ inch thick.

Frame plates 9 by 1 inch thick. Three tanks, collectively 600 gallons. Coke-box 13 cwts. India-rubber draw-spring.

Light Tank-Locomotive.—Firebox 1 foot 11 inches by 3 feet 1 inch wide, barrel 2 feet 10 inches diameter, tubes 8 feet 10 inches long. Cylinders 9 inches by 12 inches stroke; wheels, four coupled, 3 feet diameter, with 4-inch axles, at 6-feet centres. Side frame-plates 10 by $\frac{3}{4}$ inches.

Plate XLV.*

Passenger Locomotives, by J. J. Cudworth, Ashford, and by D. K. Clark, London.—The first of these engines is specially designed for the proper combustion of coal; the peculiar feature is the elongated firebox, with a long sloping grate. The nature and performance of this style of engine has been fully treated in the body of this work, at pages 28* and 35*, with respect to its qualifications as a coal-burner and steam-producer. Its advantageous arrangement as a carriage, also, deserves notice. The engine herein illustrated is placed on six wheels, four coupled, at 13 feet extreme centres, and the axles spaced equi-distantly. The obvious facility afforded for disposing the hind wheels and axle forward, under the load, enables Mr. Cudworth to place the axles at a moderate distance apart, and to distribute the weight of the engine equally on the wheels. Thus, the engine weighs $25\frac{1}{2}$ tons, in working order, and the load is almost precisely $8\frac{1}{2}$ tons on each pair of wheels:—

Leading wheels,	...	8 tons 8 cwts.
Driving „	...	8 „ 11 „
Hind „	...	8 „ 10 „
Total weight,	...	25 tons 9 cwts.

This perfect equality of load is attained without having recourse to any of the usual expedients for equalizing the load; and, as the total driving weight amounts to 17 tons 1 cwt., it is obvious that the engine is well qualified for both goods and passenger traffic.

Cylinders 14 inches by 20 inches stroke, coupled wheels 5 feet 6 inches, leading-wheels 3 feet 8 inches. Firebox 6 feet 6 inches long, 3 feet $2\frac{1}{2}$ inches wide; inside divided longitudinally into two compartments, each compartment being 1 foot $7\frac{1}{4}$ inches wide. Grate 6 feet long by $19\frac{1}{4}$ inches on each side, having altogether $19\frac{1}{4}$ square feet area. Firebox-shell 7 feet $1\frac{1}{2}$ inch long. Barrel 8 feet long. There are 210 tubes, $1\frac{3}{4}$ inch diameter, 9 feet $1\frac{3}{4}$ inch long. Sectional area through ferrules, 1·75 square feet. The heating surface is as follows:—

Firebox,	...	107 square feet.
Tubes (inside),	...	755 „
Total,	...	862 „

The *Passenger Locomotive*, on the same plate, by D. K. Clark, is made with outside horizontal cylinders, and four coupled wheels. The boiler is made on the long-boiler type, with a small firebox; the cylinders are more than usually spaced apart, to make room for double pairs of guide-bars outside the leading-wheels; the outside frame-plates are thus set out to a width of 7 feet 8 inches outside, and the leading-axle is correspondingly extended beyond the wheels, affording a clear way about the axle-boxes, and large bearings. The valve boxes are placed under the floor of the smokebox. The boiler is well elevated above the machinery, and its central line is placed upwards of 6 feet above the level of the rails. Thus, there is abundance of room everywhere, with simplicity of detail, and easy access. The whole of the valve-gear, including the reversing lever, is balanced on the weigh-bar shaft by a counterweight, so heavy and at such an intermediate angle on the shaft, as to balance in all positions. A footstep, also, is applied to the reversing lever, to aid in working the reversing gear under steam. The driving-wheels are placed well forward, as much so as is consistent with a proper length of connecting-rod, to facilitate which the cylinders also are placed well forward, and so a more nearly equal distribution of weight is effected on the coupled wheels; and further to promote this object, a heavy cast-iron footplate is applied behind the firebox. The engines run with perfect steadiness on the Great North of Scotland Railway, for which they were designed, and command abundance of steam, more particularly since the adaptation of the engines by Mr. William Cowan, the locomotive superintendent, to the consumption of coal without smoke on Mr. Clark's system. The driving and hind wheels are at 8 feet 6 inches centres, and the whole wheel base is 14 feet 6 inches. The weight of the engine in working order is distributed as follows:—

Leading wheels,	...	6 tons 10 cwts.
Driving „	...	9 „ 15 „
Hind „	...	7 „ 5 „
Total,	...	23 tons 5 cwts.

The cylinders are 15 inches by 20 inches stroke; coupled wheels 5 feet 6 inches, leading-wheels 3 feet 6 inches. The firebox is 3 feet long, 3 feet 6 inches wide, and 4 feet deep to the grate, having 10½ square feet of grate surface. There are 150 brass tubes, 1¾ inch outside diameter, ⅝ inch clear, 11 feet 4¼ inches long, in a 3 feet 8 inch barrel; the chimney is 13 inches, and the blast-orifice is 4¼ inches diameter.

Inside heating surface of firebox,	...	58 square feet.
" " tubes,	...	750 "
Total surface,	...	808 "

The engine can take a maximum gross weight of train, of 210 tons, up an incline of 1 in 100 at 20 miles per hour. On ordinary duty, it takes nine carriages, weighing 62 tons, or with engine and tender, 98 tons gross, stopping at stations averaging three miles apart, at an average speed of 19·1 miles per hour, on a line with several severe gradients and curves, with a gross consumption of 17·7 lbs. of coke or good coal per train-mile, or ·18 lb. per ton gross per mile, evaporating 8 to 8½ lbs. of *cold* water per lb. of fuel. With heated feed-water, the consumption would be reduced, say 15 per cent., to 15 lbs. per mile, or about ·15 lb. per ton gross per mile.

Plate XLVI.*

American Passenger Locomotive, by Danforth, Cooke, & Co.—The American locomotives have been very fully described in the body of the work, pages 47* to 73*. In this engine, the characteristic features of American practice are embodied. The firebox is large, the grate is of cast iron, with a dead plate next the tube-plate. The firebox-shell is tapered off to the diameter of the barrel. The "petticoat" blast-pipe, to diffuse the action of the blast, is used, with the conical spark-catcher and wire-netting on the chimney; the outside horizontal cylinder with long connecting-rod, the four-coupled wheels and the swivelling truck, or bogie, the forged framing, the cow-catcher in front, and the cab on the footplate.

The gauge of way is 6 feet; the firebox is 4 feet 9 inches long, 3 feet 11 inches wide, and 5 feet high above the grate, which has 18·33 square feet area. The barrel is 4 feet in diameter, and there are 150 tubes 11 feet long. The cylinders are 17 inches by 22 inches stroke, with separate blast-pipes, 2½ to 2¾ inches diameter; leading-wheels 5 feet 6 inches, and bogie 30 inches, at 5 feet 2 inch centres. The length of wheel-base to the pivot of the bogie is 18 feet 1½ inch.

Plate XLVII.*

American Wood-burning Passenger Locomotive, by William Mason & Co.—Gauge of way 4 feet 8½ inches. The firebox is 4 feet 6 inches long by 3 feet 1¾ inch, giving 14·25 square feet area. There are 136 tubes, 2 inches diameter, 11 feet 3 inches long. Cylinders 15 inches by 22 inches. Wheels of cast iron, 5 feet 6 inches. Steam-ports 14 by 1¼ inches, blast-orifice 3¼ inches. Bogie wheels 30 inches, at 5 feet 8 inch centres. Wheel-base 18 feet long to pivot.

Plate XLVIII.*

American Freight Engine, by M. W. Baldwin & Co.—This engine is placed on eight wheels all coupled, of which the four first are placed in a swivel frame, turning on two pivots, like a parallel ruler, so that the axles do not radiate to the curves, as an ordinary bogie or truck, but preserve their parallelism to the other axles. The hind-axle is placed under the firebox, and while the wheel-base is thus limited, an equal distribution of weight on the wheels is obtained. The cylinders are outside, and inclined, 18 inches by 20 inches stroke; wheels 43 inches diameter. Driving-axle 6 inches, other axles 5⅝ inches diameter; extreme axles, 14 feet 2 inches apart. The firebox is of $\frac{5}{16}$-inch iron plate, except tube-sheet, ⅜ inch; it is 6 feet 6 inches long, and 2 feet 10½ inches wide, presenting 18·66 square feet of grate-surface. The bars are of cast iron, and are cast in pairs. The roof-stays are transverse, and their ends rest on the square edges of the side-plates. There are 110 wrought-iron flue-tubes, 2¼ inch outside diameter, 11 feet 6 inches long. The barrel of the boiler is telescopic, mean diameter 3 feet 7½ inches. The boiler is of $\frac{5}{16}$-inch iron plate, except the smokebox tube-plate, ½ inch. The blast-orifice is adjustable, and is placed in a short chimney in the smokebox, beneath and separate from the chimney above. The gauge of way is 4 feet 8½ inches, and the engine is shown in the plan on a curve of 150 feet radius, with the swivel-axles in position.

PLATE XLIX.*

This plate comprises cross sections and elevations of Mason's and Baldwin's engines. It contains, also, an illustration of the well-designed truck employed under the engines of the Baltimore and Ohio Railway, from Captain Galton's *Report on the Railways of the United States.*

PLATE L.*

Contains the tender for Mason's engine, and several views of Baldwin's tender. They are both placed on eight wheels, or two trucks of four wheels each. The brake-blocks are hung by chains, and the brakes are worked through the same medium, in order to accommodate the brake to the action of the trucks.

INDEX.

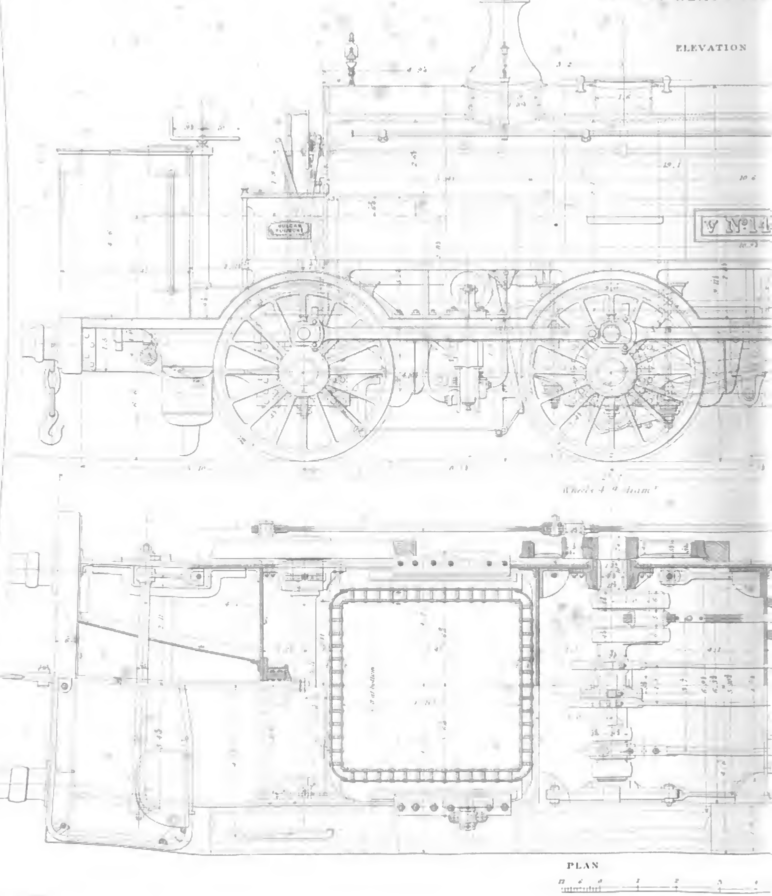
TANK-LOCOMOTIVE BY I. K. B

MADE BY THE VULCAN FOUNDRY COMP

(HENRY DUBS, MANAGE

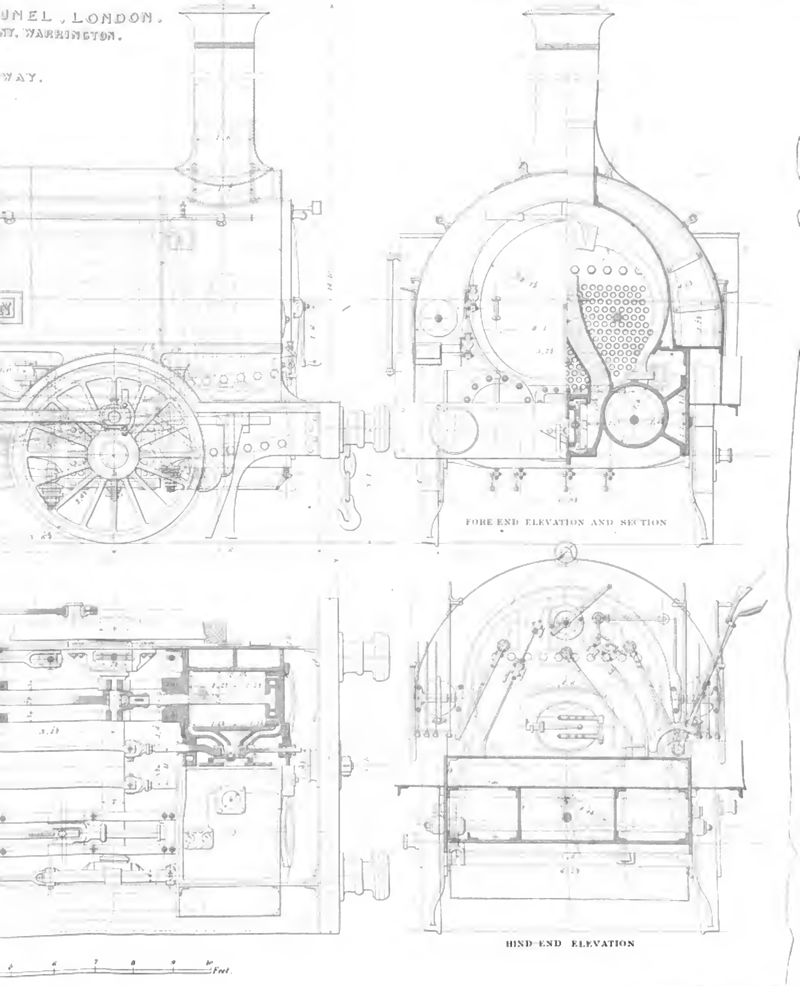
FOR THE

VALE OF NEATH RAI



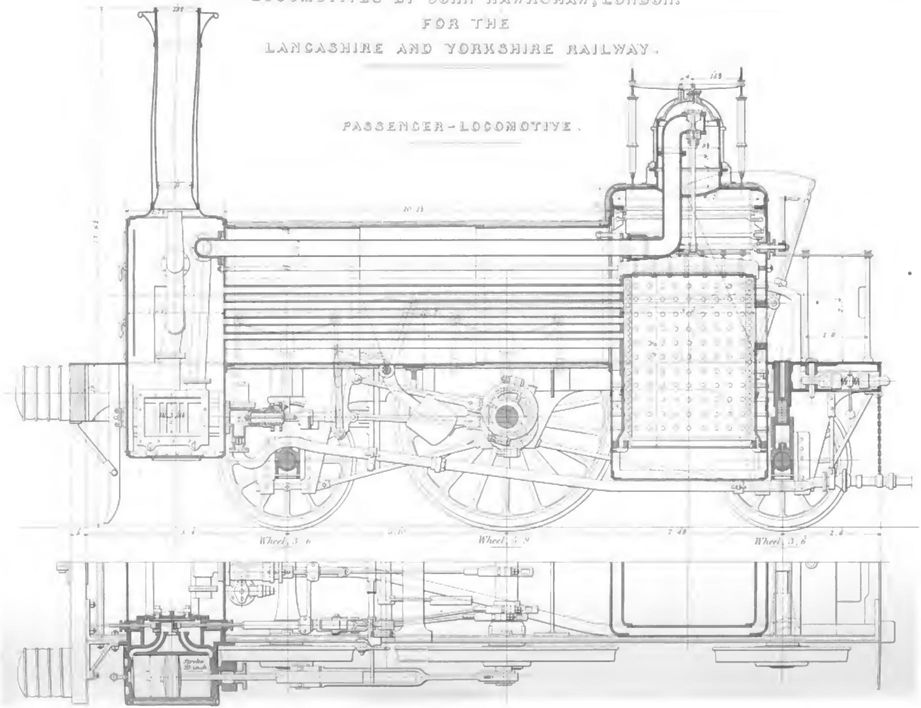
K. Clark

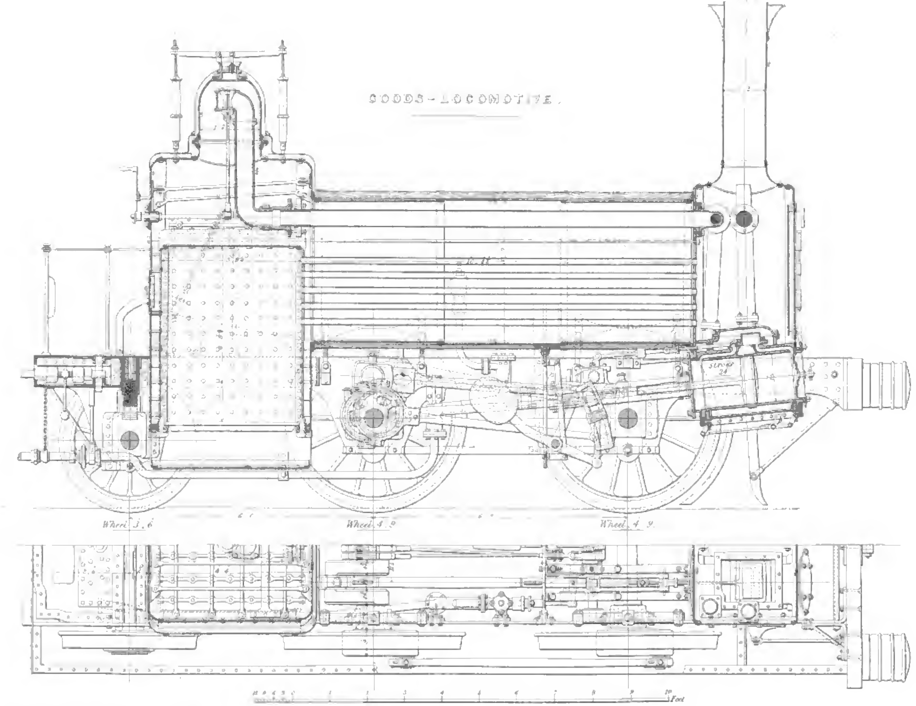
BLACKIE & SON, GLASG


UNEL, LONDON.
NY, WARRINGTON.
WAY.
FORE END ELEVATION AND SECTION
HIND END ELEVATION
Feet.

LOCOMOTIVES BY JOHN HAWKSHAW, LONDON.
FOR THE
LANCASHIRE AND YORKSHIRE RAILWAY.

PASSENGER-LOCOMOTIVE.

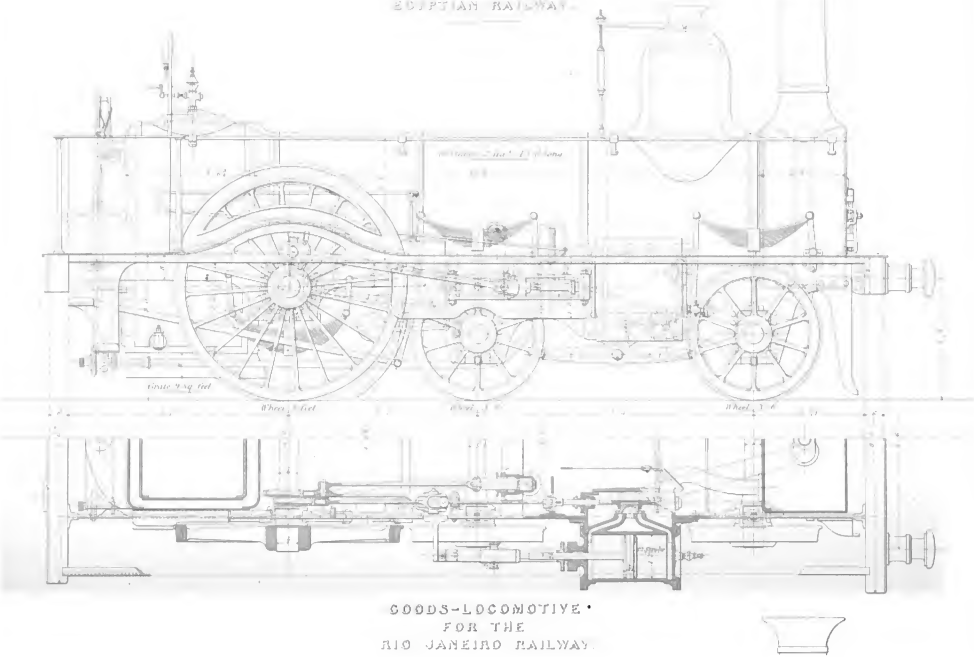




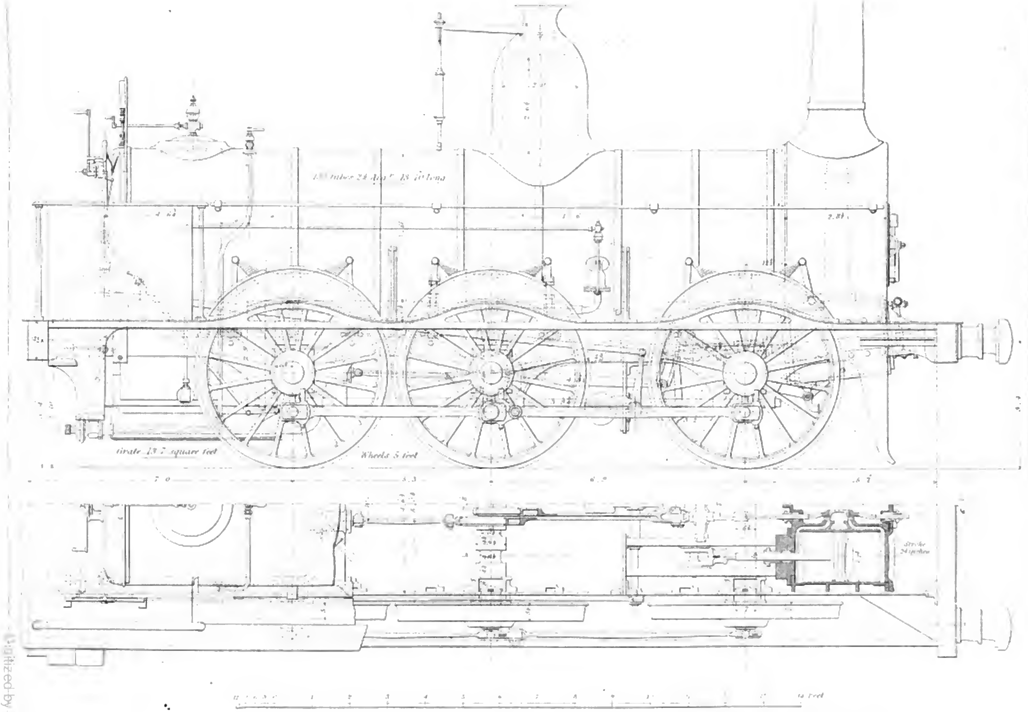
D K Clark
W. A. Beever sc

LOCOMOTIVES BY ROBERT STEPHENSON & Co, NEWCASTLE ON TYNE.

PASSENGER-LOCOMOTIVE
FOR THE
EGYPTIAN RAILWAY.

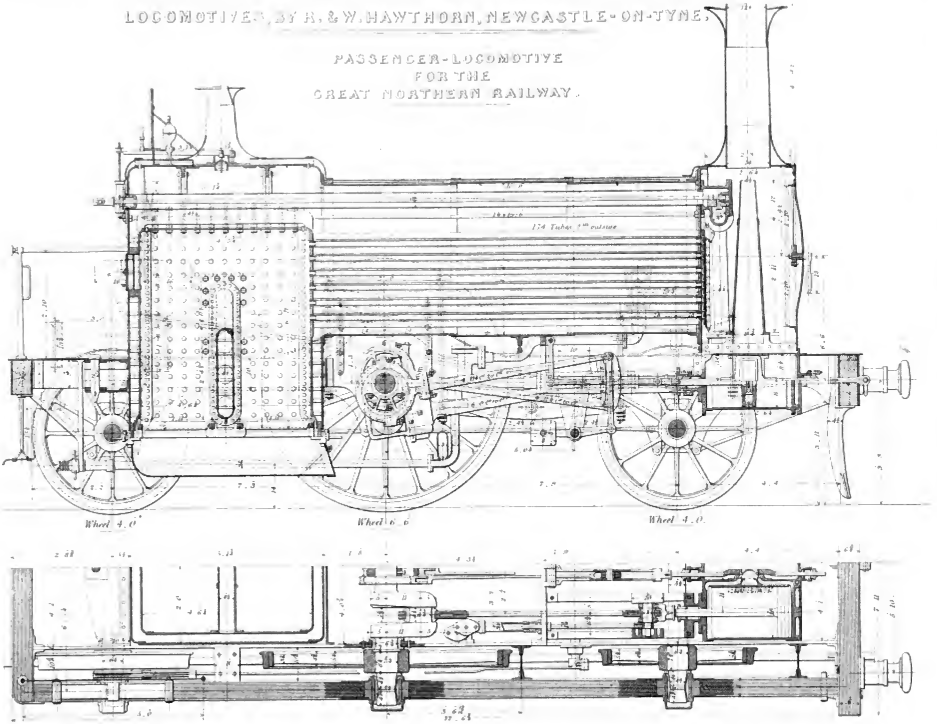


GOODS-LOCOMOTIVE
FOR THE
RIO JANEIRO RAILWAY.

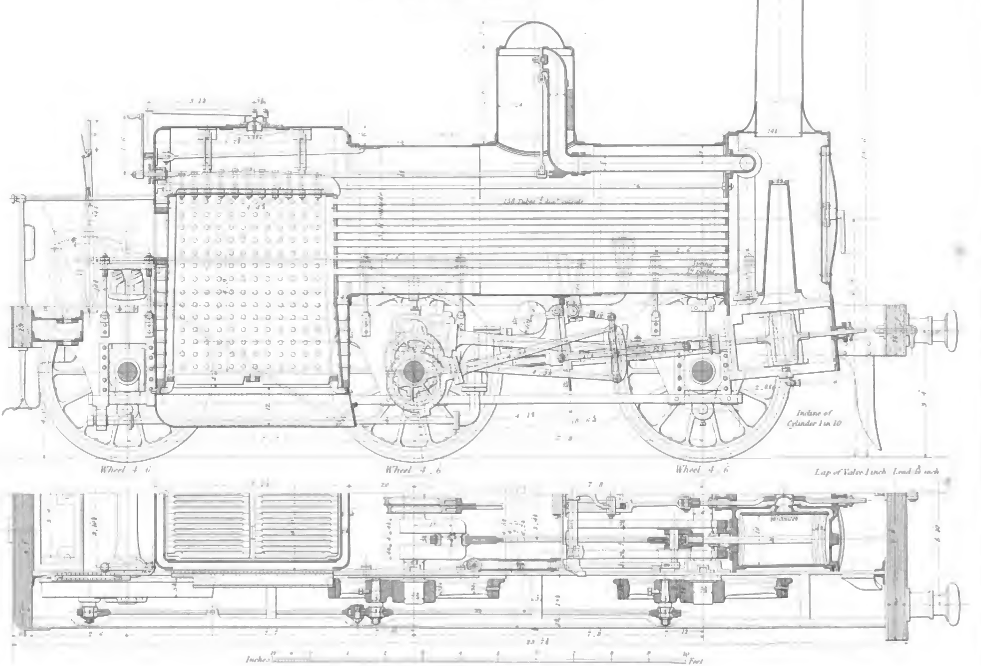

Grate 13.7 square feet
Wheels 5 feet

LOCOMOTIVES, BY R. & W. HAWTHORN, NEWCASTLE-ON-TYNE,

PASSENGER-LOCOMOTIVE
FOR THE
GREAT NORTHERN RAILWAY.



FOR THE
BLYTH AND TYNE RAILWAY



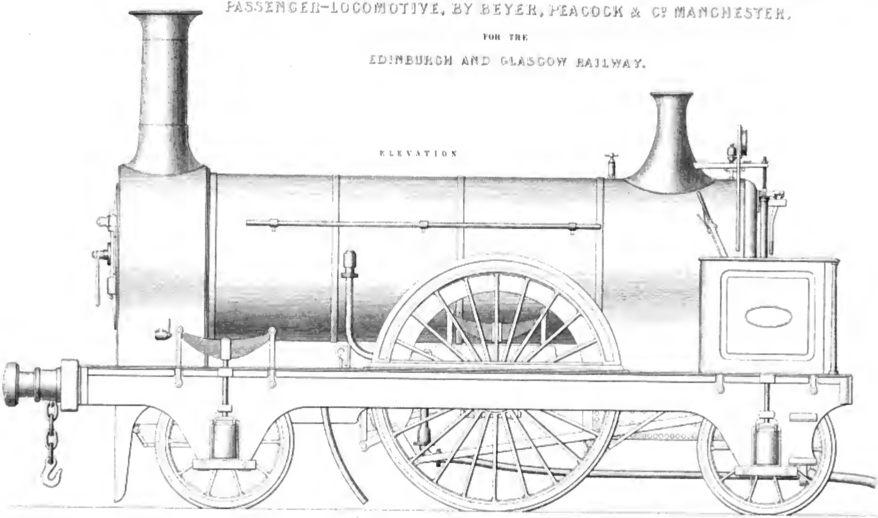
D K Clark
W A Beevor

PASSENGER-LOCOMOTIVE, BY BEYER, PEACOCK & Cº MANCHESTER,

FOR THE

EDINBURGH AND GLASGOW RAILWAY.

ELEVATION



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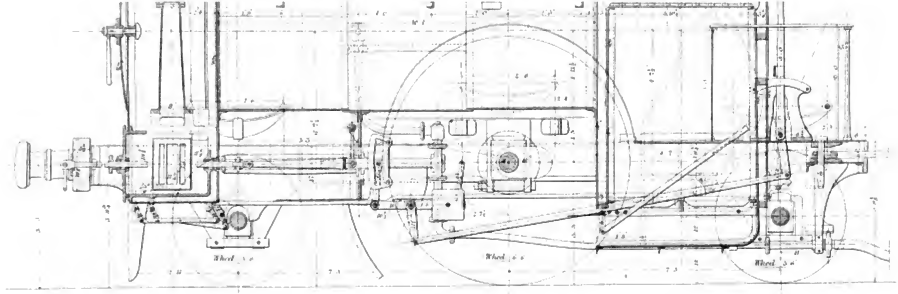

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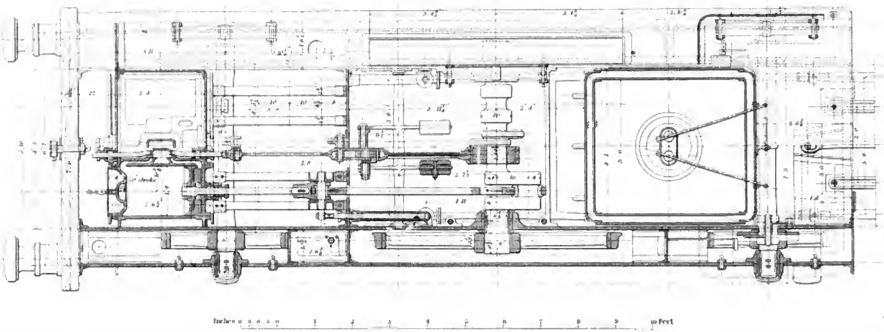
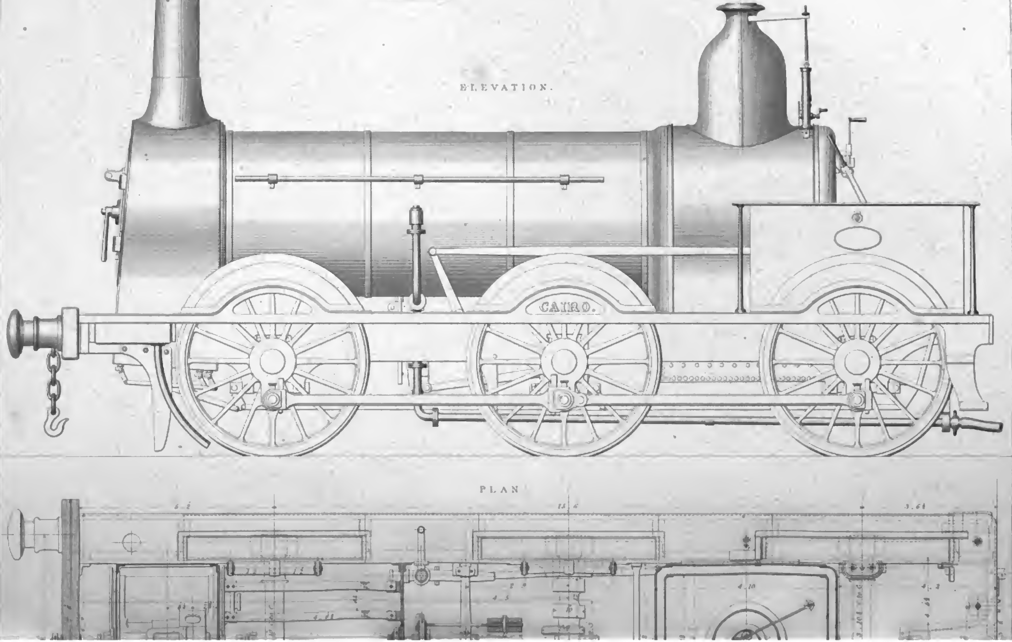
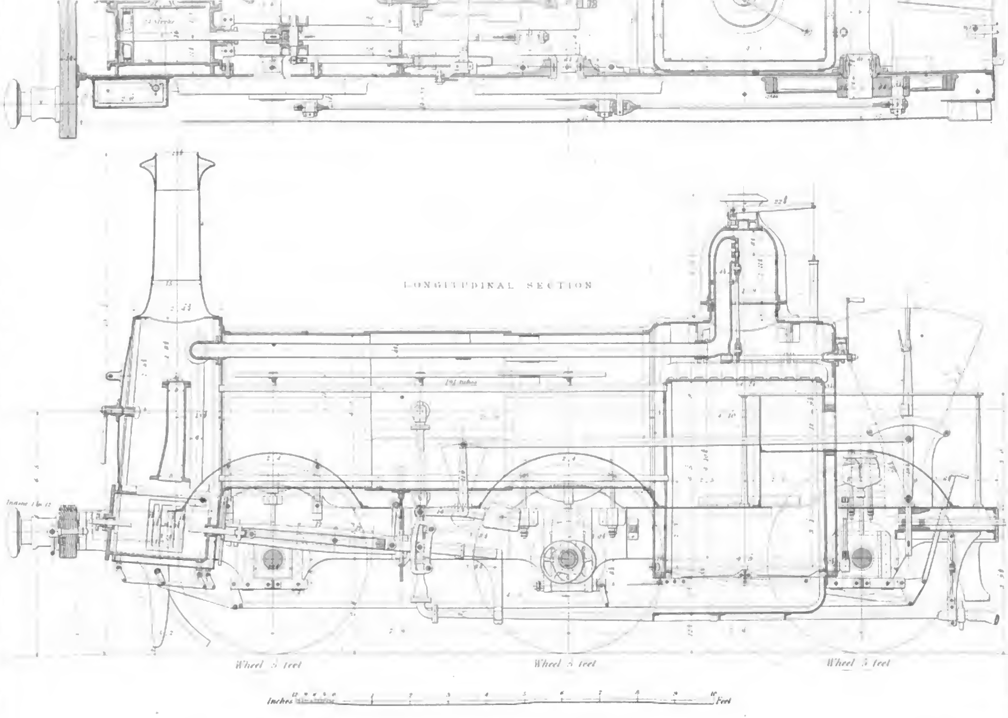


W. A. Clark

BLACKIE & SON, GLASGOW, EDINBURGH & LONDON

GOODS LOCOMOTIVE BY BEYER, PEACOCK & Co, MANCHESTER,
FOR THE
EGYPTIAN RAILWAY.





D. K. Clark

W. A. Beever, Sc.

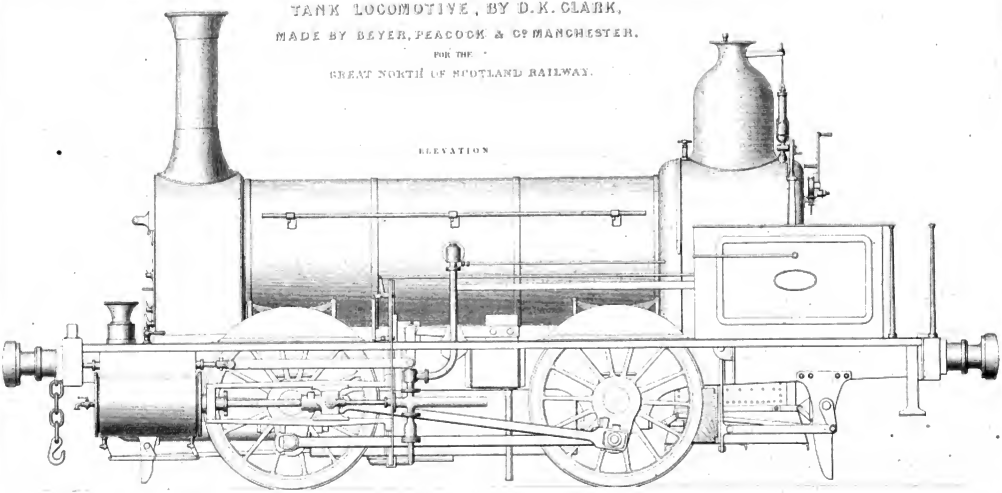
TANK LOCOMOTIVE, BY D. K. CLARK,

MADE BY BEYER, PEACOCK & Co. MANCHESTER,

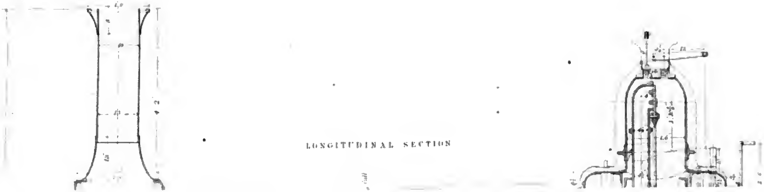
FOR THE

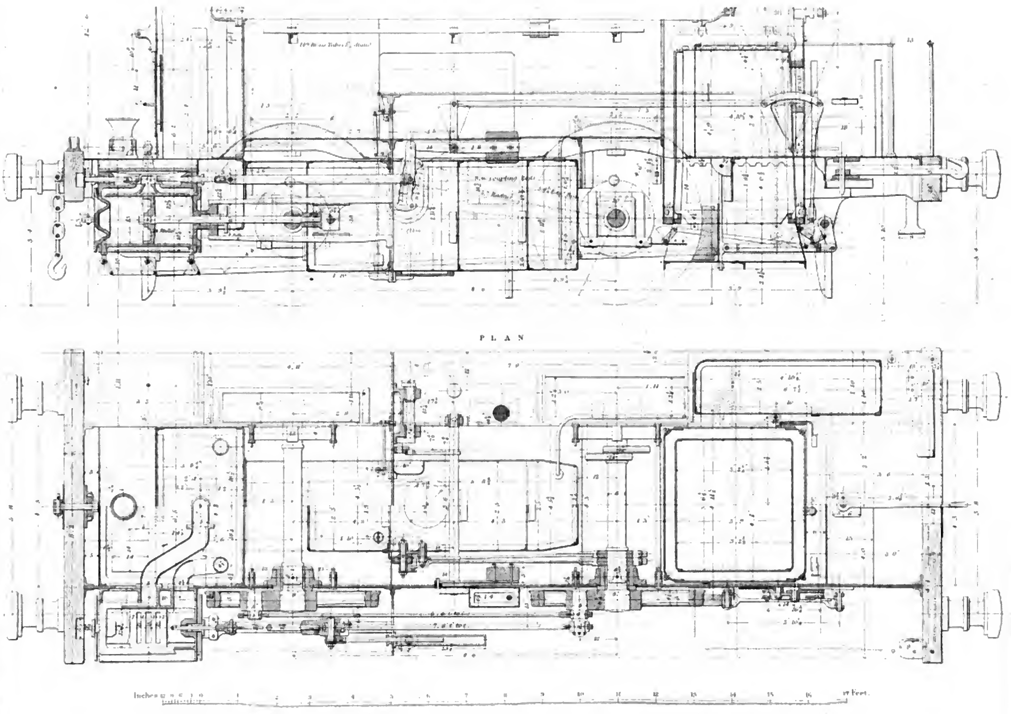
GREAT NORTH OF SCOTLAND RAILWAY.

ELEVATION



LONGITUDINAL SECTION




PLAN
Inches
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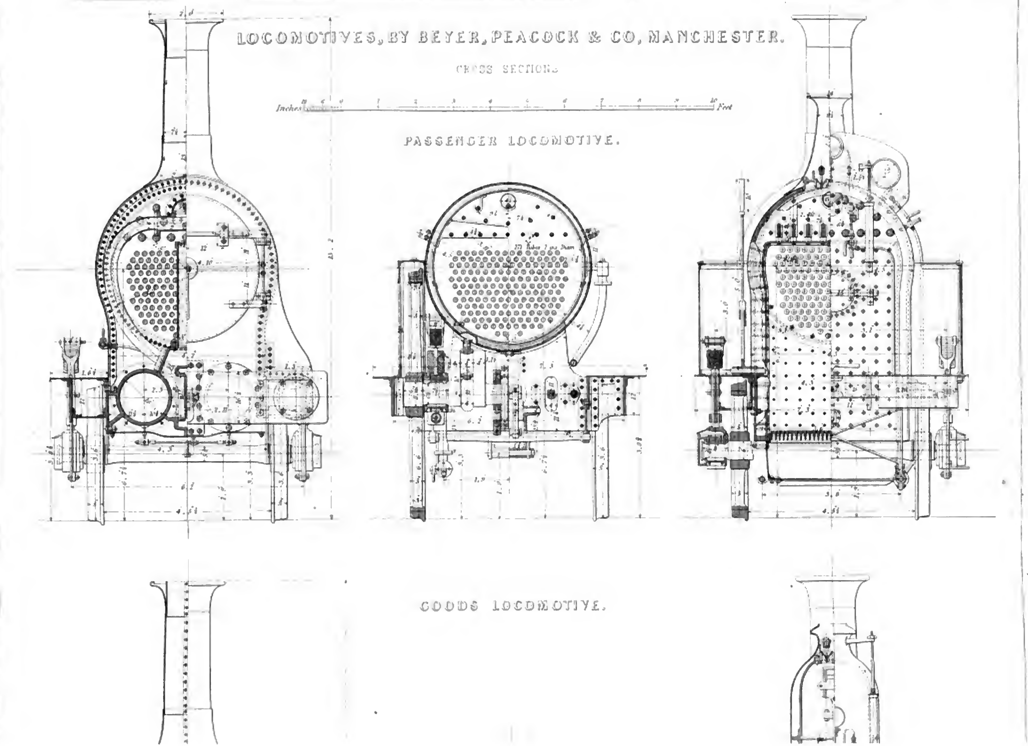
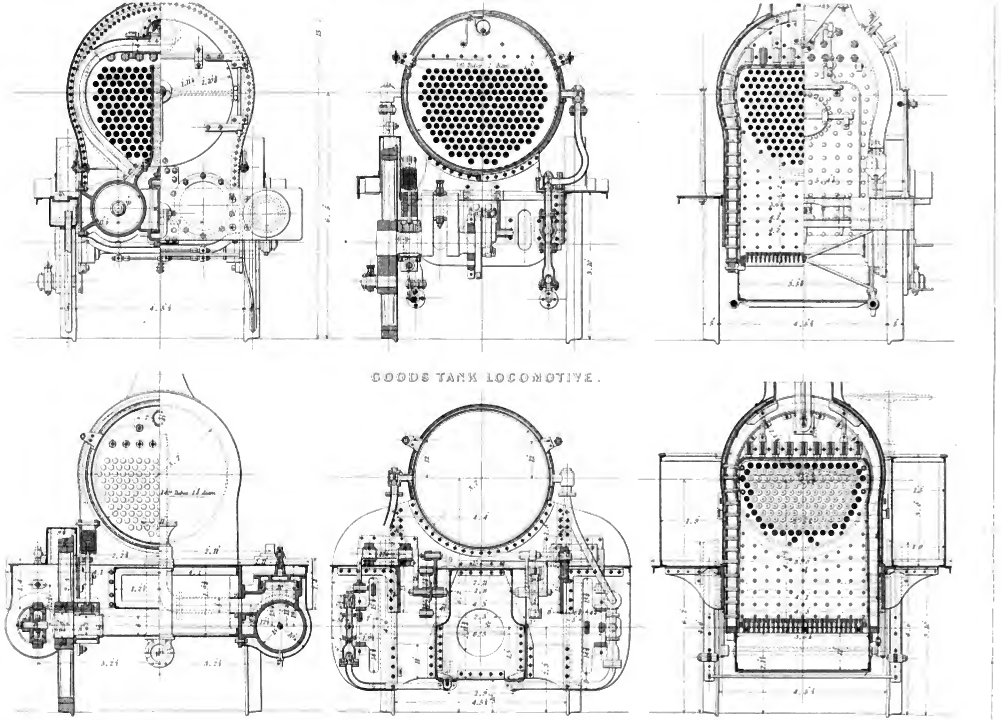

LOCOMOTIVES, BY BEYER, PEACOCK & CO, MANCHESTER.
CROSS SECTIONS
Inches
Feet
PASSENGER LOCOMOTIVE.
GOODS LOCOMOTIVE.



GOODS TANK LOCOMOTIVE.

D. K. Clark

W. J. Rowan sc.

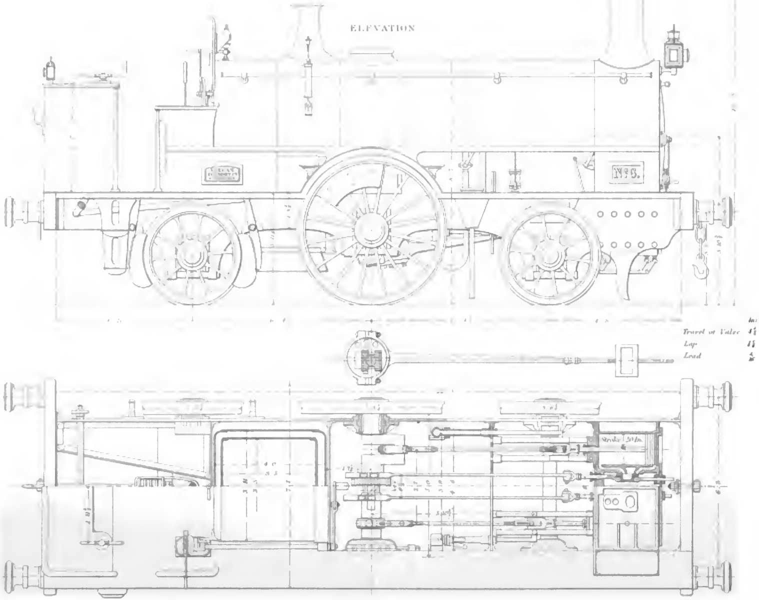
BLACKIE & SON, GLASGOW, EDINBURGH & LONDON.

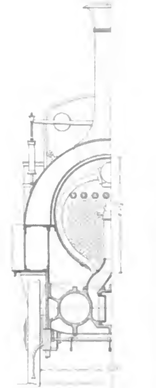
PASSENGER TANK-LOCOMOTIVE, BY THE VULCAN FOUNDRY COMPANY, WARRINGTON,

(Henry Dubs, Manager)

FOR THE

DUBLIN AND WICKLOW RAILWAY.

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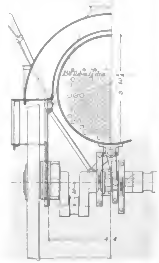
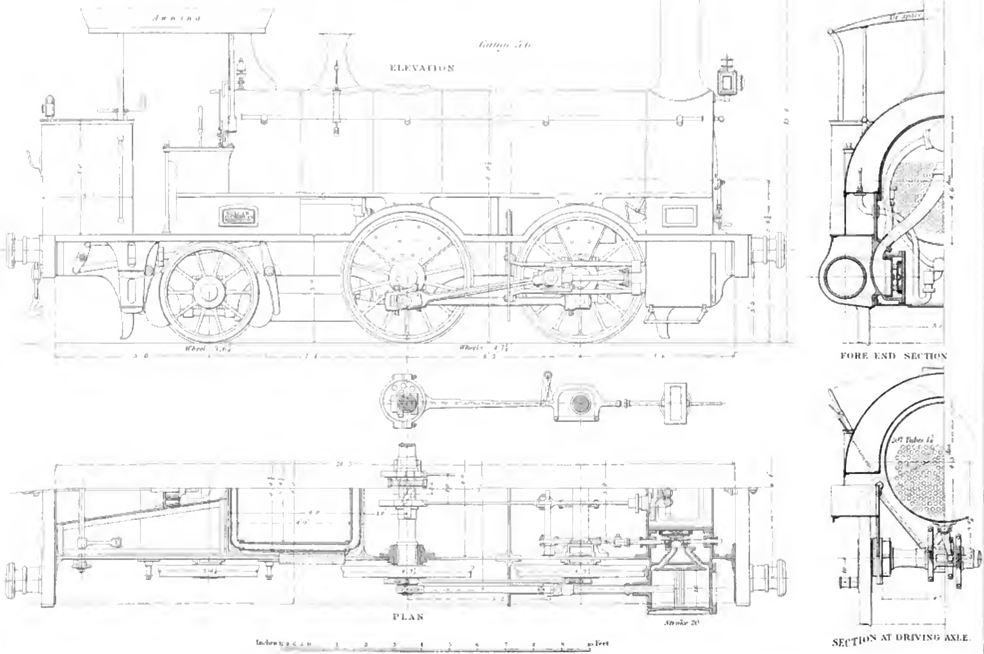

SECTION AT DRIVING AXLE

COUPLED TANK LOCOMOTIVE

BY THE VULCAN FOUNDRY COMPANY, WARRINGTON



D. K. Clark

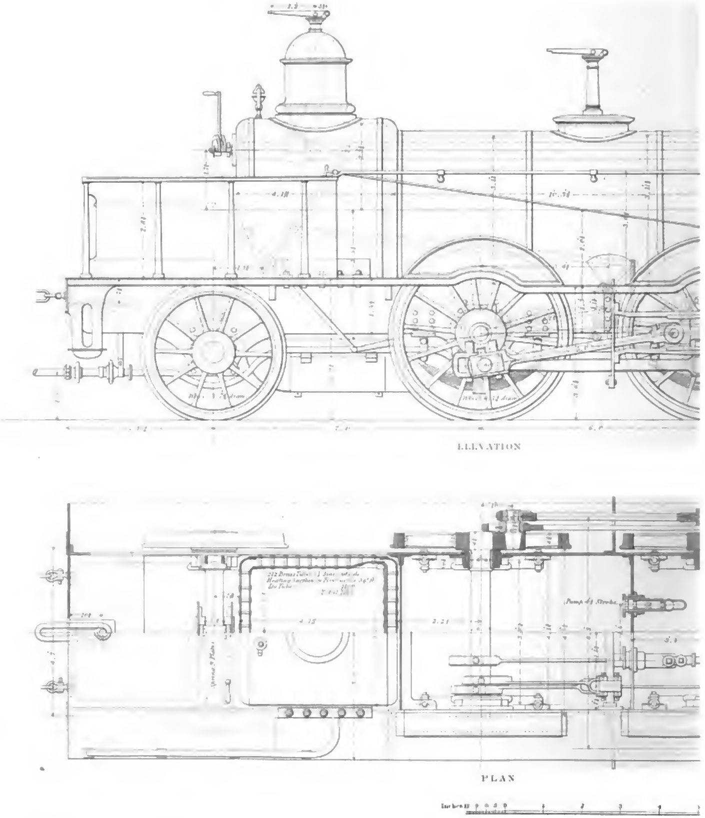
J. W. Lowry sc.

BLACKIE & SON, GLASGOW, EDINBURGH & LONDON.

GOODS LOCOMOTIVE BY A

FOR

SCOTTISH CEN



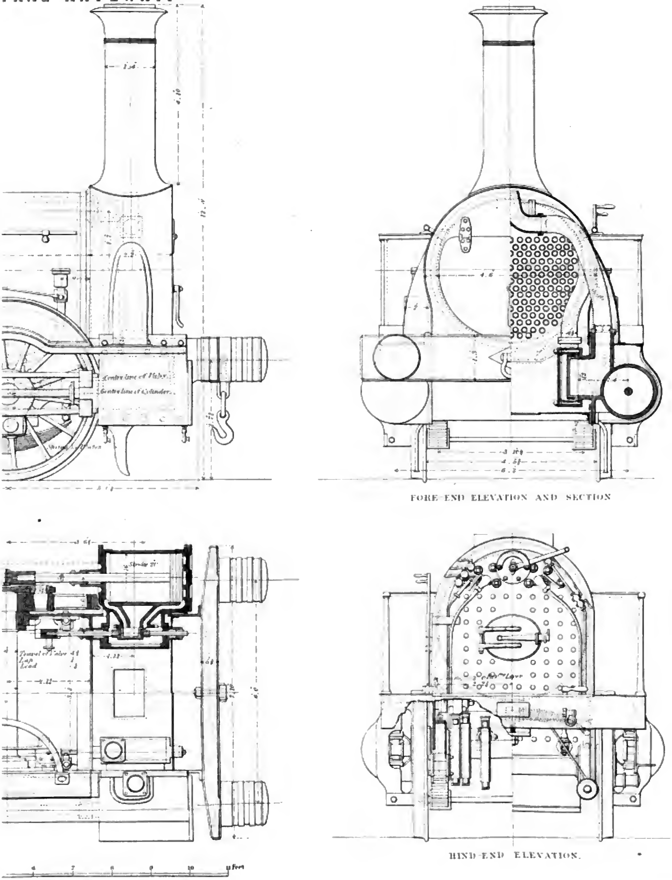
ELEVATION

PLAN

D.K. sculp.

BLACKIE & SON, GLASGOW

LEXANDER ALLAN, PERTH,
THE
TRAL RAILWAY.



FORE-END ELEVATION AND SECTION

HIND-END ELEVATION.

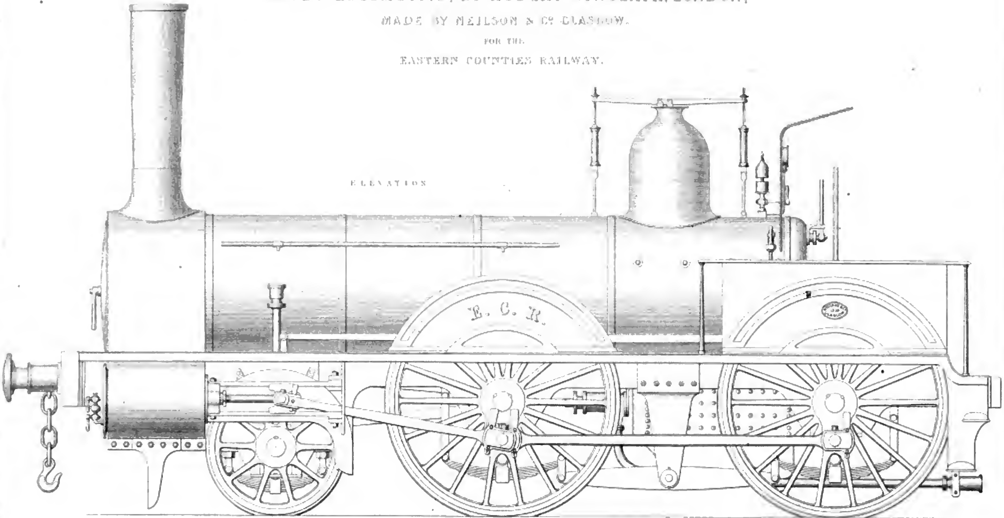
EDINBURGH & LONDON

GOODS-LOCOMOTIVE, BY ROBERT SINCLAIR, LONDON,

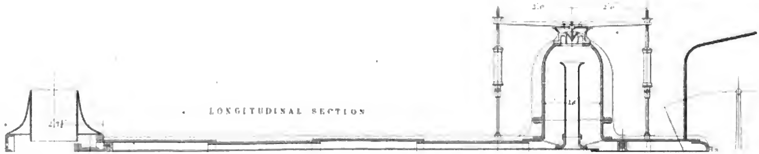
MADE BY NEILSON & Co GLASGOW.

FOR THE

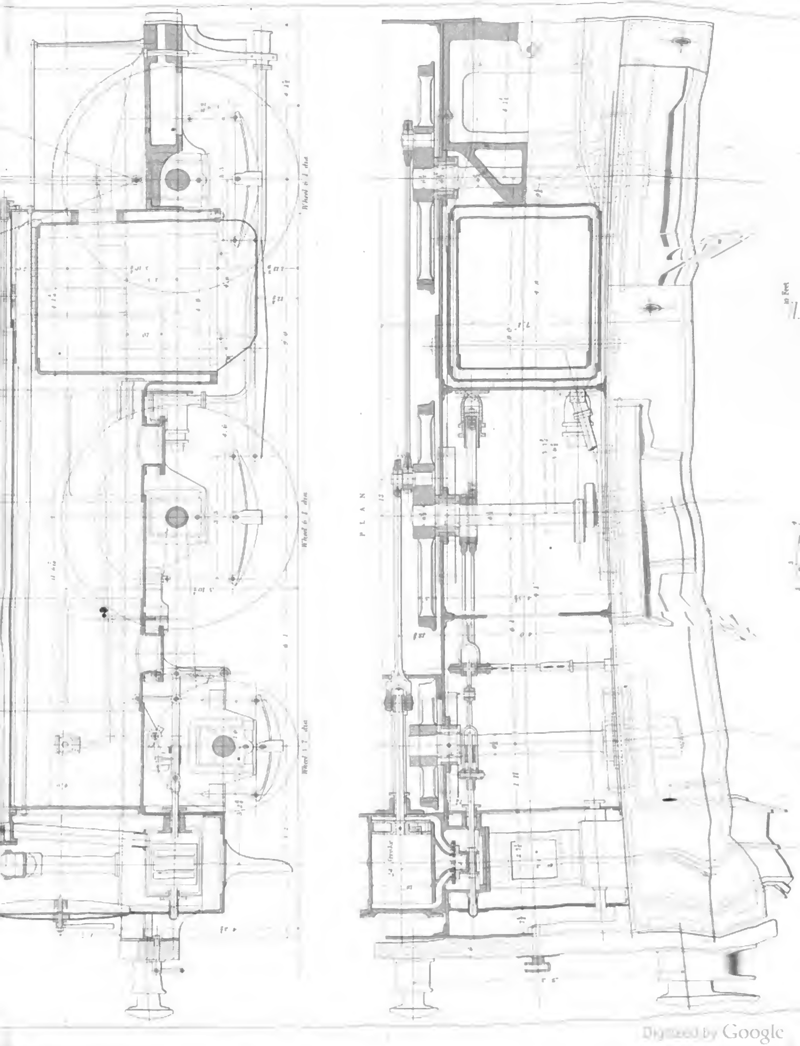
EASTERN COUNTIES RAILWAY.



ELEVATION

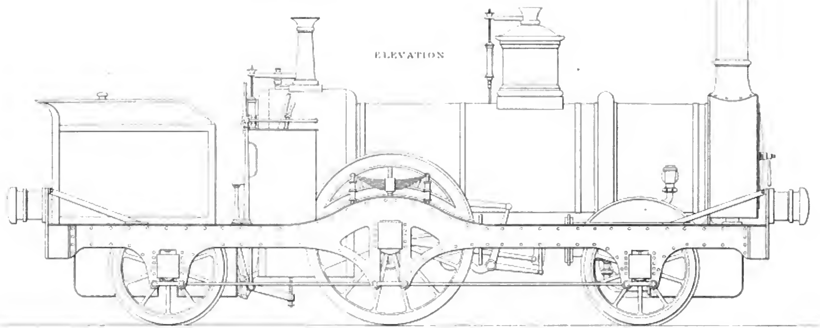


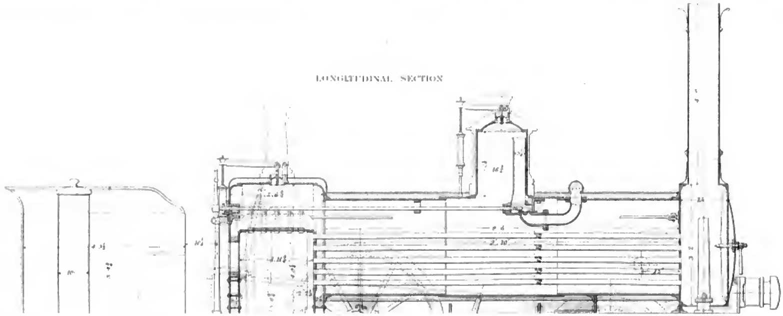
LONGITUDINAL SECTION

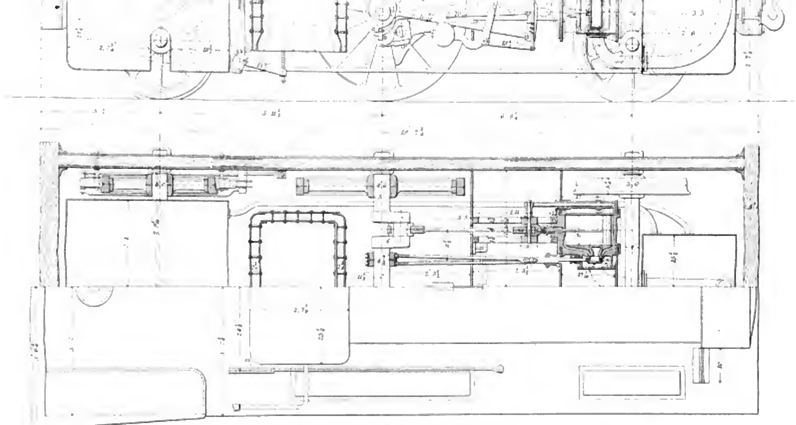

PLAN

EXPRESS TANK LOCOMOTIVE, BY GEORGE ENGLAND & Co. LONDON.

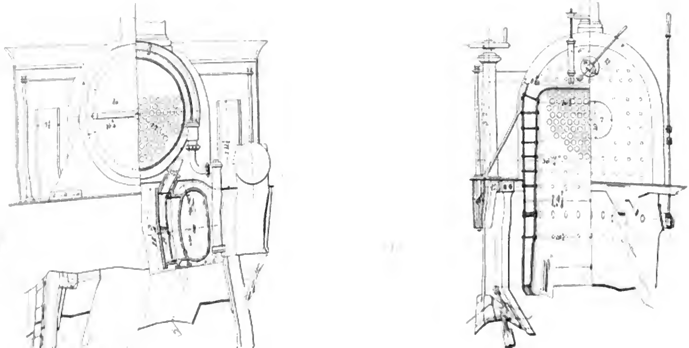
FOR PASSENGER TRAINS.



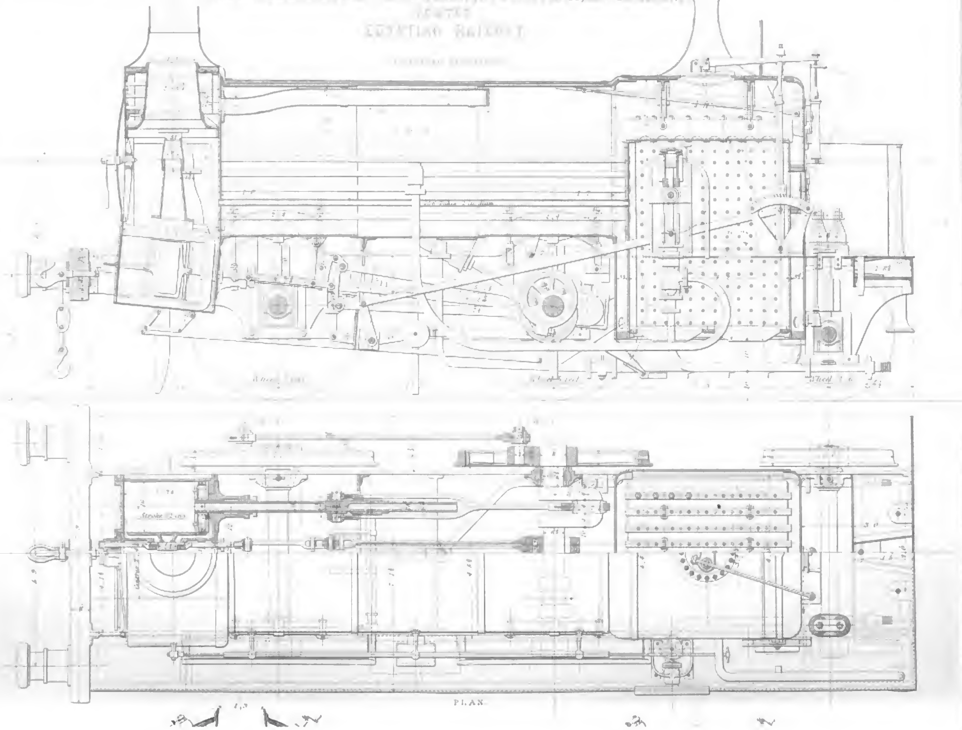


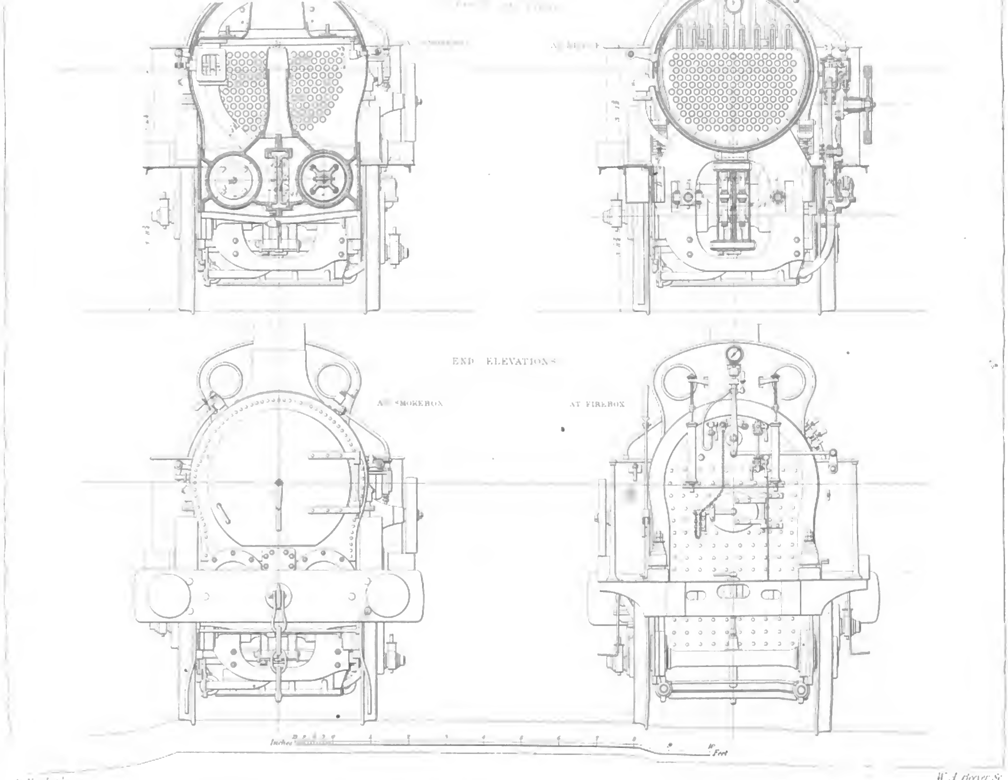


HORIZONTAL SECTION AND PLAN

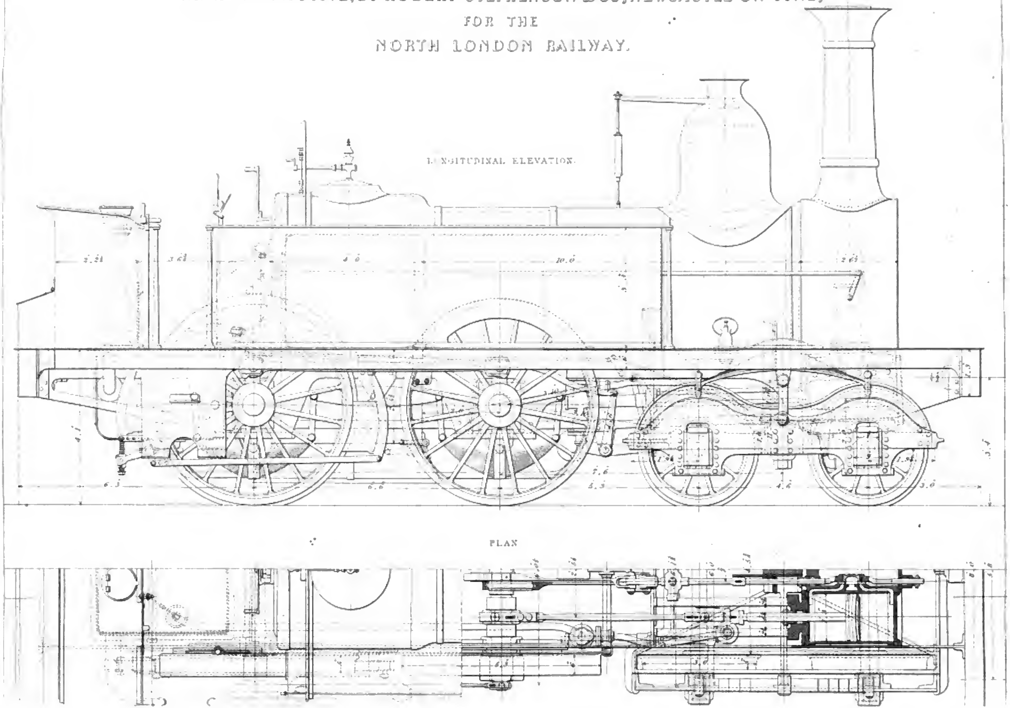


PASSENGER LOCOMOTIVE BY SHARP, STEWART & Co, MANCHESTER,
FOR THE
EGYPTIAN RAILWAY.

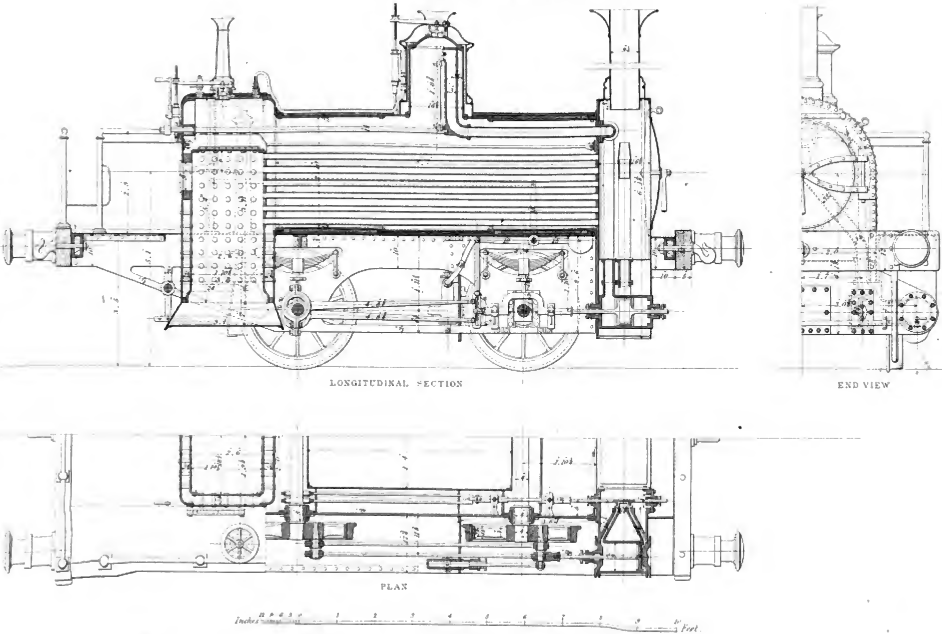



END ELEVATIONS
AT SMOKEBOX
AT FIREBOX
Inches
Feet
D K Clark
W. A. Beever Sc

TANK-LOCOMOTIVE, BY ROBERT STEPHENSON & Co, NEWCASTLE ON TYNE,
FOR THE
NORTH LONDON RAILWAY.



TANK-LOCOMOTIVE, BY GEORGE ENGLAND & Co, LONDON, FOR THE SANDY & POTTON RAILWAY.

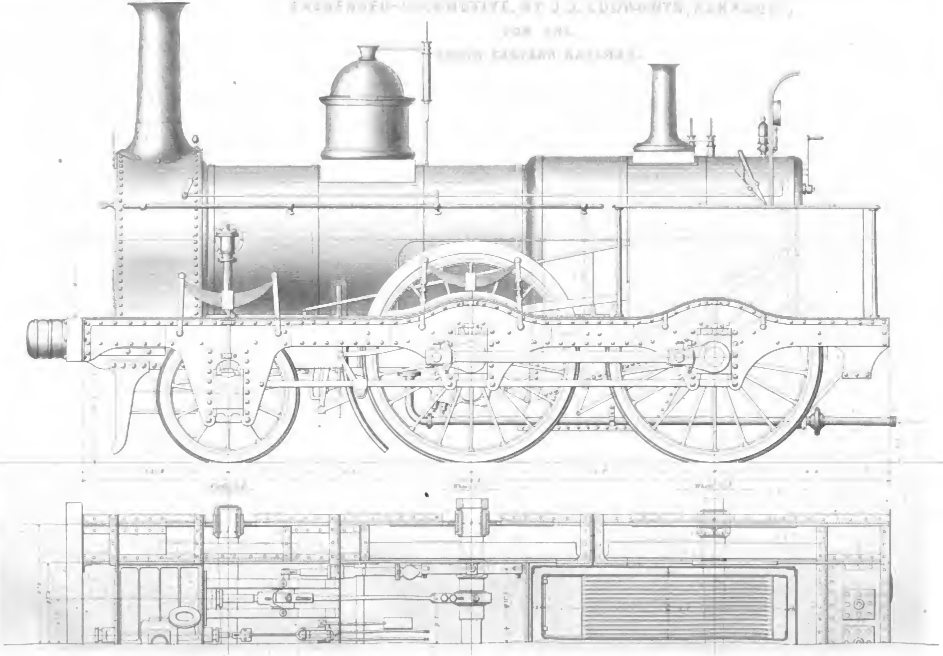


D. K. Clark

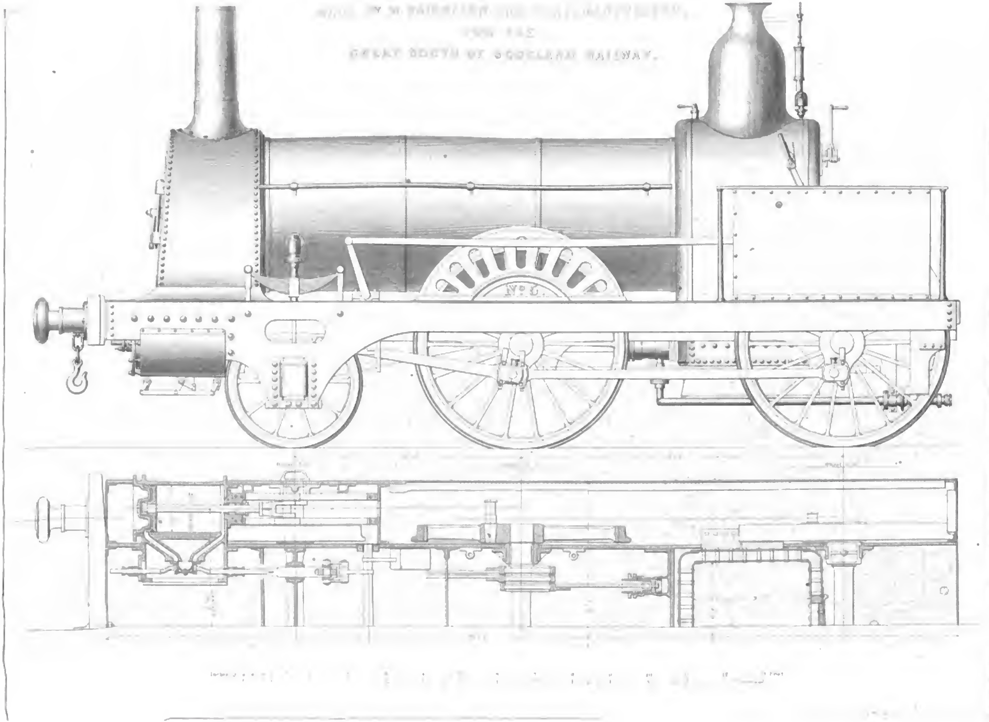
W. A. Beever sc.

Blackie & Son, Glasgow, Edinburgh & London.

PASSENGER-LOCOMOTIVE, BY J. I. CUDWORTH, ENGINEER,
FOR THE
SOUTH EASTERN RAILWAY.



PASSENGER-LOCOMOTIVE, BY D.K. CLARK, LONDON.


FOR THE
RAILWAY.

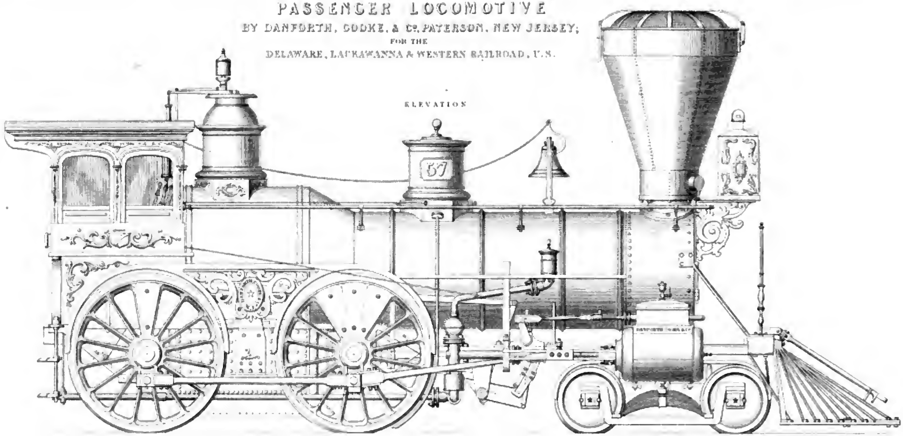
PASSENGER LOCOMOTIVE

BY DANFORTH, COOKE, & Co. PATERSON, NEW JERSEY;

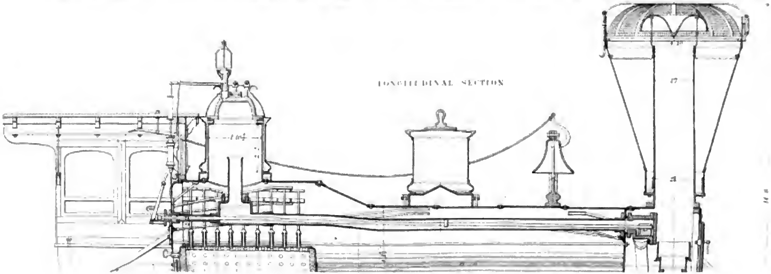
FOR THE

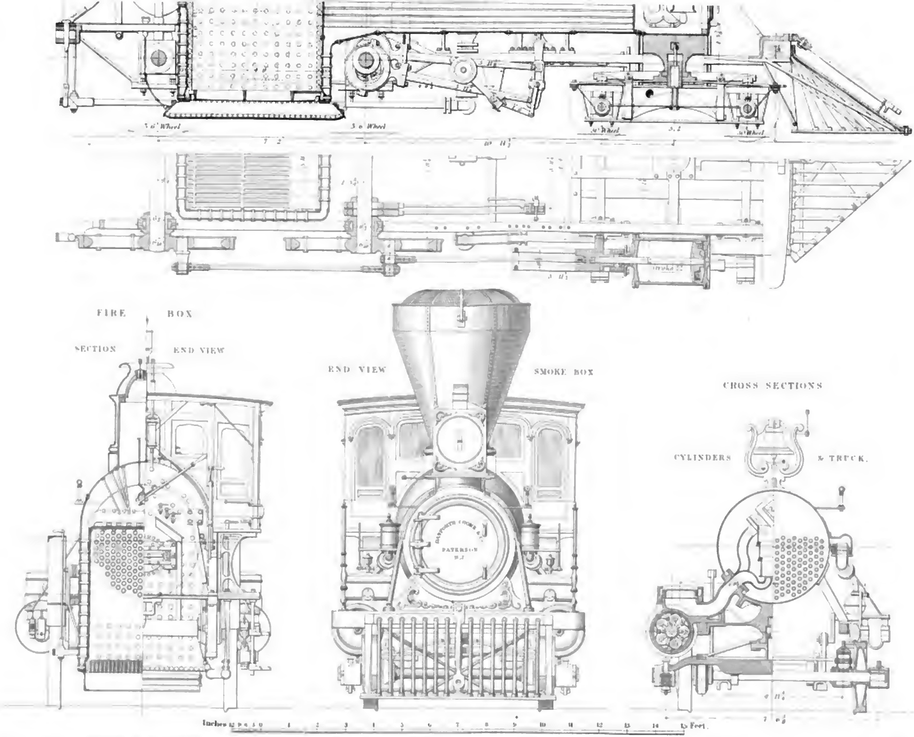
DELAWARE, LACKAWANNA & WESTERN RAILROAD, U.S.

ELEVATION



LONGITUDINAL SECTION





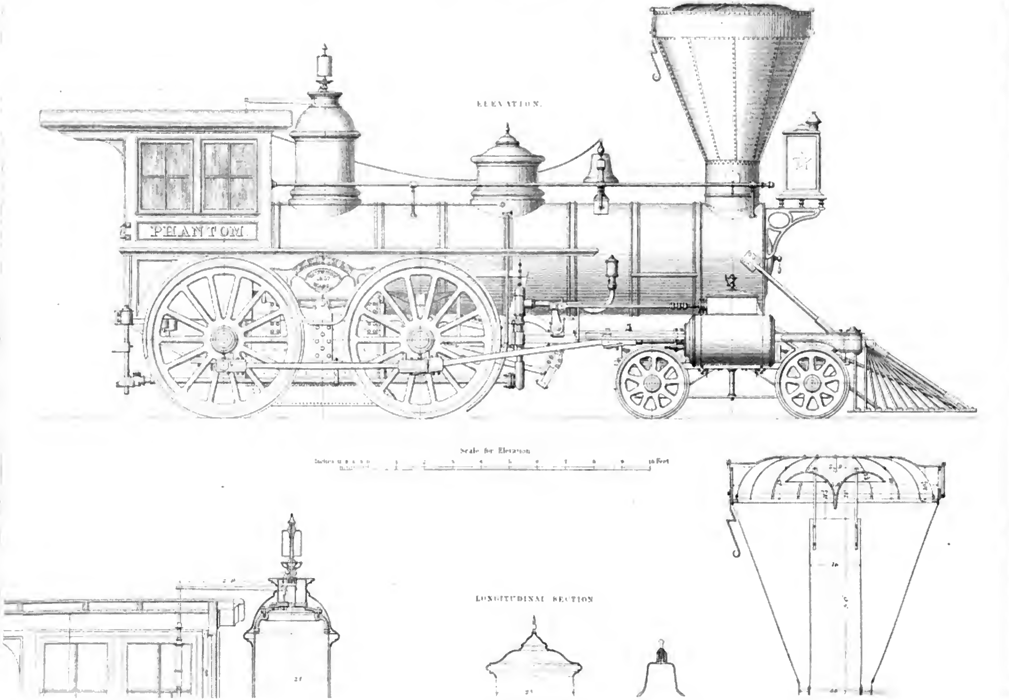
D K Clark

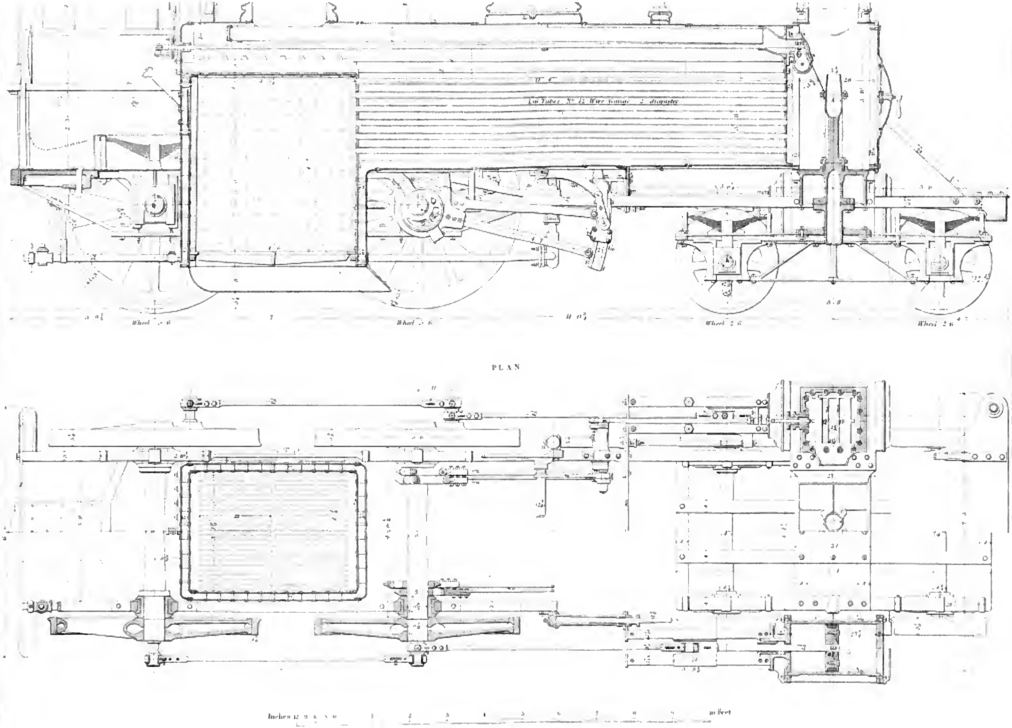
J W Lowry fc

BLACKIE & SON GLASGOW EDINBURGH & LONDON

WOOD-BURNING PASSENGER-LOCOMOTIVE, BY W^m MASON & Co

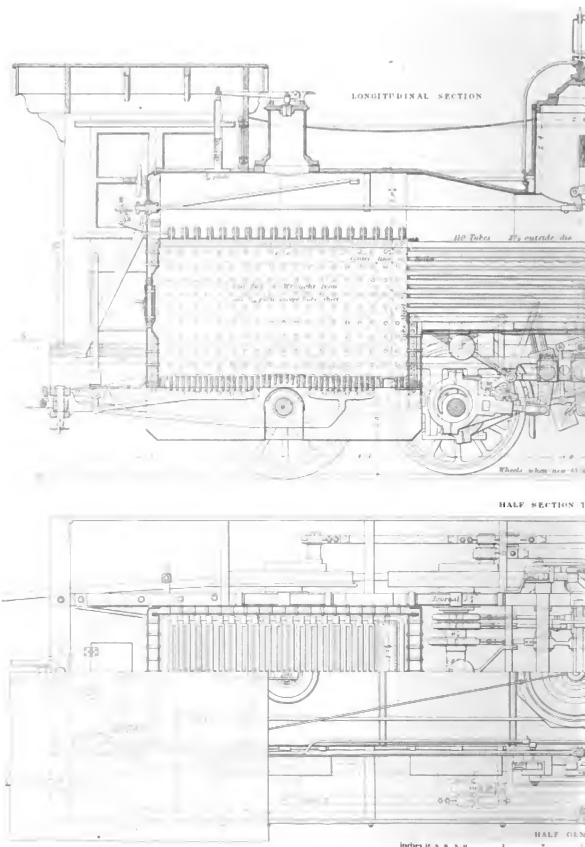
TAUNTON, MASS. U.S.




PLAN
Inches 12 9 6 3 0 1 2 3 4 5 6 7 8 9 10 Feet

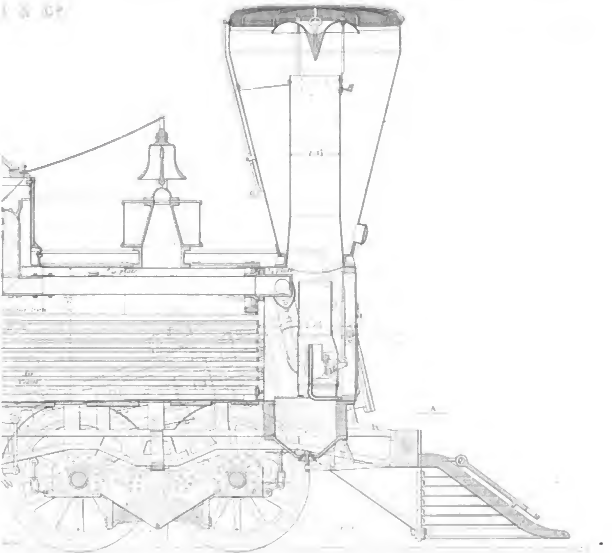
FREIGHT ENGINE, BY M. W. BALDWI

PHILADELPHIA, U. S.

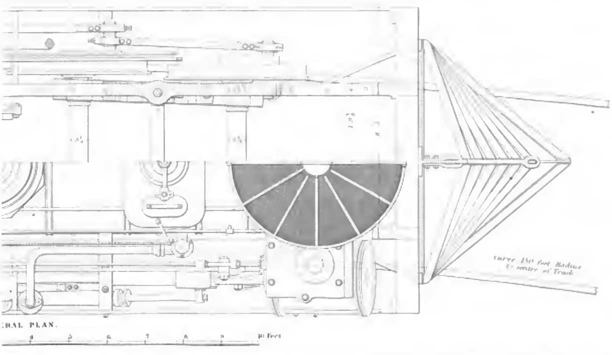


Drawn by Richard Heskin
Zerah Colburn

BLACKIE & SON, GLASG



ROUGH LINE AA



RAL PLAN.

4 5 6 7 8 9 10 Feet

J.W. Lowry sculp.

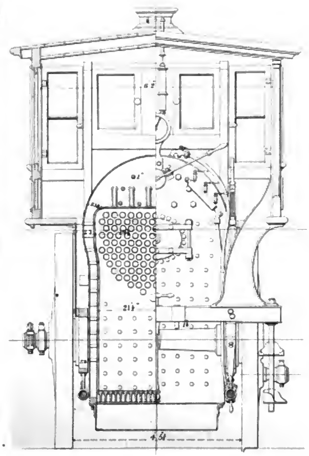
W. EDINBURGH & LONDON.

AMERICAN LOCOMOTIVES — CROSS SECTIONS.

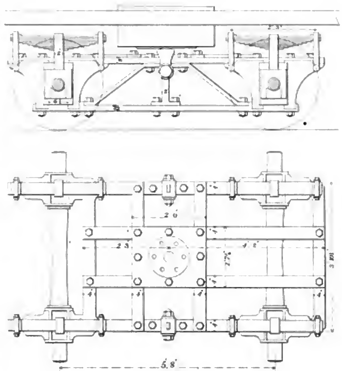
BALTIMORE & OHIO RAILWAY.

MASONS ENGINE.

FIRE BOX & CAB

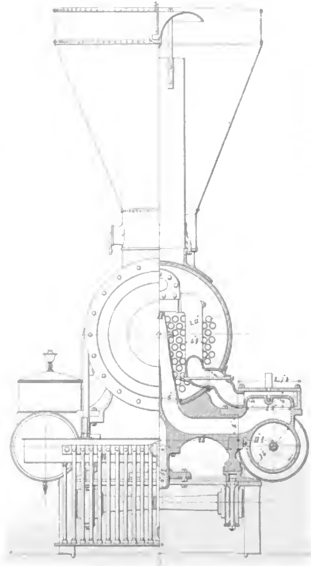


TRUCK FOR TEN WHEEL ENGINE

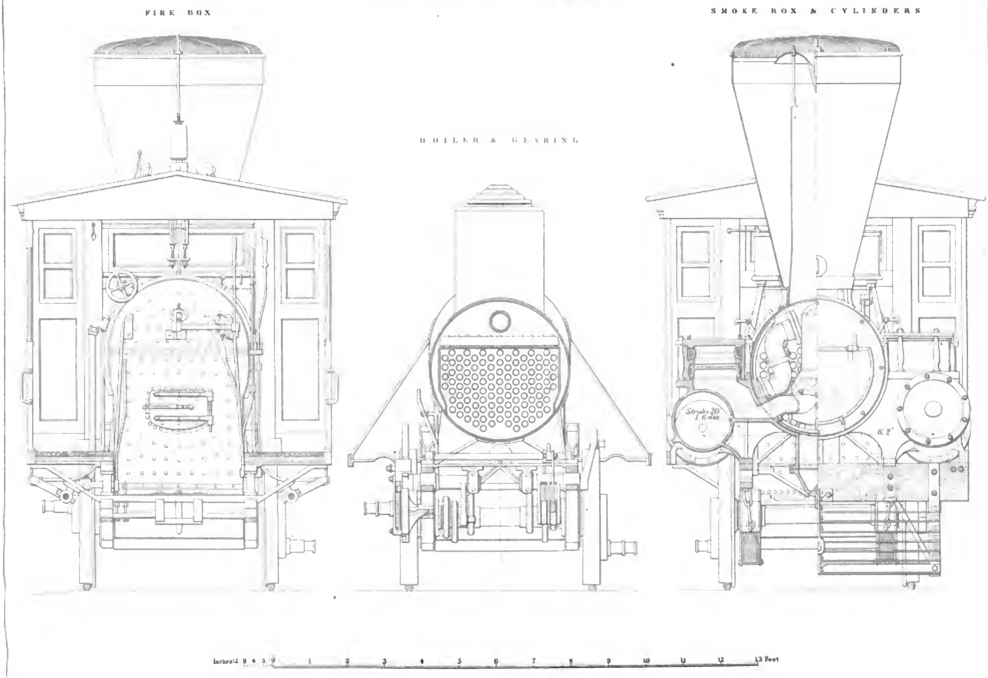


MASONS ENGINE.

SMOKE BOX & CYLINDERS



BALDWINS ENGINE.



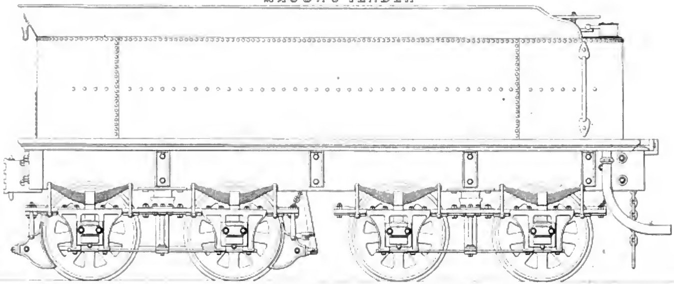
D. K. Clark

C. B. Smith fc

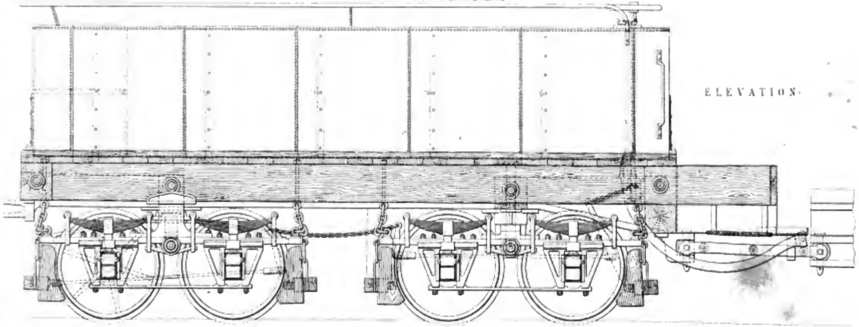
BLACKIE & SON, GLASGOW, EDINBURGH & LONDON

TENDERS FOR AMERICAN LOCOMOTIVES.

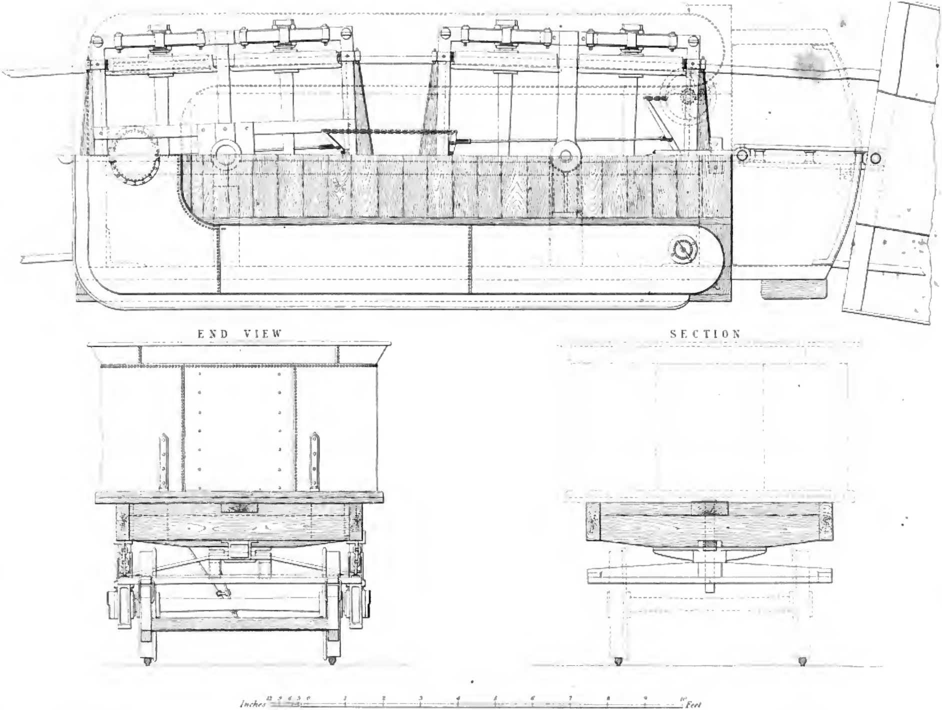
MASON'S TENDER



BALDWIN'S TENDER

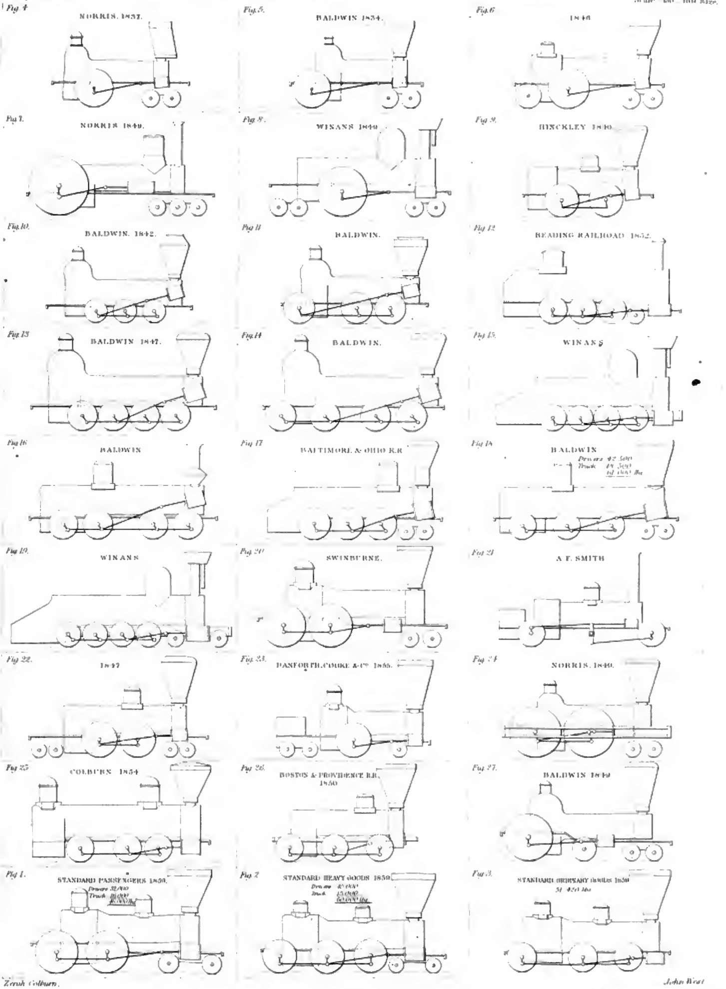


ELEVATION.


END VIEW
SECTION
Inches
Feet

ILLUSTRATIONS OF AMERICAN LOCOMOTIVES AS CARRIAGES.

Scale 1/130th full size.



Zerah Colburn. John West

BLACKIE & SON. GLASGOW, EDINBURGH & LONDON.